ACTA ORTHOPAEDICA SCANDINAVICA

VOL. 46

# ACTA ORTHOPAEDICA SCANDINAVICA



MUNKSGAARD, Copenhagen

Vol 46, Nos 1-6, 1975

Munksgaard
International Booksellers and Publishers, Ltd
35 Nørre Søgade, DK-1370 Copenhagen K, Denmark

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Vol 46 Nos 1-6

Acta orthop scand 46 1–10, 1975

Research Laboratory, Orthopaedic Hospital Copenhagen and
Medicotechnical Institute, Glostrup Denmark

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Inge Reimann, J Stolgaard, A Northeved & [illegible] J Johnsen

Accepted 14 xi 74

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The aim of this report is to present an apparatus able to demonstrate boundary lubrication by synovial fluid and to expound different factors which may influence the results achieved

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The apparatus is constructed by the Medicotechnical Institute, Academy for the Technical Sciences, Copenhagen, in accordance with an

Below the motion cylinder a slide is placed on an object table The fluid to be studied is placed on the slide between it and the rubber covered end of the motion cylinder It is the intention to keep the two surfaces the slide and the rubber covered end of the motion cylinder, parallel during the entire measuring process Moreover, in the rubber-covered end of the motion cylinder a hollow has been turned with the purpose of making the rubber contact point with the slide a circle with an inside diameter of 13 0 mm and an outside diameter of 15 4 mm

The holder of the slide is fastened to the bottom plate of the frame by means of a torsion bar, which at the same time acts as a spring with a calculated force The torsion bar thus allows the lowest part of the measuring system (slide and holder) to rotate through a few degrees without friction and wobble

The registration of the rotation of the lowest part of the measuring system is done by means of a displacement transducer of which one section is fastened to the frame while the other section is connected to the holder of the slide by a shaft The electric signal from the displacement transducer is fed via an electronic unit to an ink recorder (Ilukushin II 130 0 A) The rotational oscillation which goes first one way and then the other with a total angular sweep of 33°, comes from a non vibrating motor The motor is, moreover, fixed to an angle bar connected with the frame by means of four vibration dampers only The speed of the motor is controlled and kept constant by the electronic unit.

The transformation of the rotational oscillation of the motor shaft to the reciprocating motion of the shaft is effected by an eccentric gear fixed to the motor shaft The transmission of the motion to the shaft is carried out by means of an operating lever device constructed to transmit the reciprocating oscillation without wobble

The aluminium frame is the bearing element of the set up and keeps the primary components in the correct positions in relation to each other It is placed on four vibration dampers on a granite slab measuring 50 × 50 × 8 cm in order to avoid the transmission of vibrations from the surroundings to the aluminium frame, and in this way to the measuring system

*Calculation*

The friction is stated in terms of the coefficient of friction ($\mu$)

Calibration of the measuring equipment is performed by placing a shaft of fixed length in a hole made for that purpose in such a way that the shaft points radially away from the slide holder A string is fastened to the end of the shaft and drawn over pulleys positioned one on each side of the aluminium frame At the end of the string a weight (3.3 g) is placed

The calculation is made on the basis of the curves traced on the ink recorder (Figure 2), the amplitude is measured in square units, peak to peak, and is multiplied by a factor K representing the constant of the apparatus K is worked out according to the formula

$$K = \frac{b\ g/cm}{r\ cm\ \ M\ g\ \ X_1}$$

in which b is the weight of the calibration plumb multiplied by the length of the lever arm (24 7), r is the mean radius of the point of contact of the rubber cover

American construction devised by C W McCutchen, National Institutes of Health, Bethesda, Maryland

## EXPERIMENTAL DESIGN

### *Technical description*

The principle on which the measuring method employed in this study is based is also used industrially The fluid to be studied is placed between two carefully specified plates of which one is set in rotation By means of the friction between the plates and the fluid this rotation will be transmitted to the other plate, which is spring loaded Using a displacement transducer the rotation angle of plate number two is measured

### *The measuring apparatus*

The primary section of the apparatus (Figure 1) is the measuring unit which is placed in the middle of a frame made of aluminium The measuring unit consists of a shaft held in a vertical position by means of two precision bearings The bottom the shaft is connected to a motion cylinder by means of a coupling which can transmit rotary oscillations only The top the shaft is provided with a weight This weight together with the weight of the shaft and the weight of the motion cylinder with the desired load (150 g) presses the motion cylinder against the base plate A rubber cover of 7/100 mm thickness is drawn around the lower end of the motion cylinder The rubber cover is fastened by means of a rubber ring

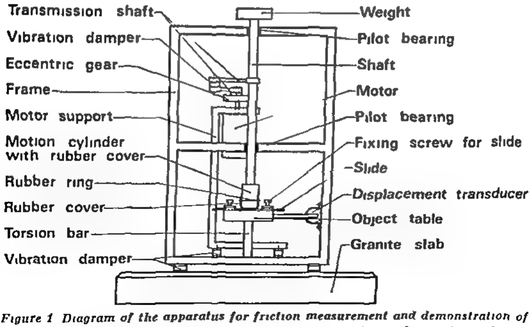


*Figure 1 Diagram of the apparatus for friction measurement and demonstration of boundary lubrication by synovial fluid The diagram shows the mechanical unit placed on the granite slab Full size 20 × 30 × 10 cm*

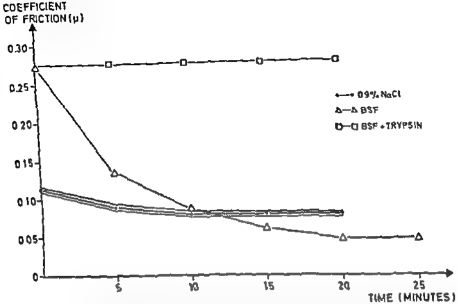


*Figure 3 The diagram illustrates the decrease in coefficient of friction when 0.9 per cent NaCl and bovine synovial fluid are used as lubricant and the absence of boundary lubrication by bovine synovial fluid digested by trypsin The marked area corresponds to the standard deviations of the values obtained by 0 9 per cent NaCl*

Numerous trials with saline and BSF as lubricant had to be made for standardization purposes before the results were reproducible

During the standardization it was found that above all it was the condition of the rubber with regard to its cleanliness and tension which could effect a change in the results

As a standard cleaning method for the rubber the following was found suitable washing with Deconex 11® for 2 min washing in running tap water for 5 min rinsing in distilled water and air drying During the trials it was found that insufficient washing resulted in a decreased lubrication effect

As changes in the tension of the attached rubber influenced the coefficient of friction in such a way that increased tension resulted in increased coefficient of friction a standard method was used for stretching the rubber during the mounting

As a control to ensure that the condition of the rubber was uniform during the different trials when BSF was used as a lubricant every trial with BSF was preceded by a trial with saline and the same rubber and after this trial washing in running tap water for 2 min and rinsing in distilled water It was required that the results of the initial test with saline fell within some standard values based on 12 measurements with saline and using a new rubber every time (*Figure 3*) If the values of the initial test with saline fell outside the calculated standard area then the rubber was renewed

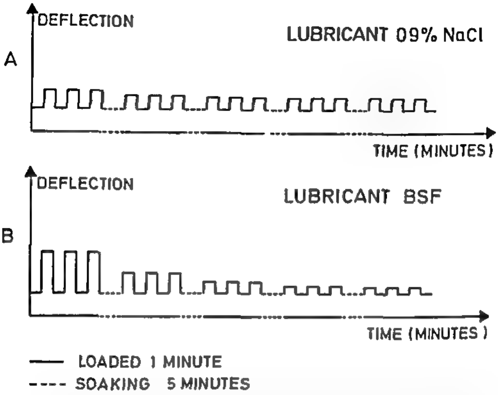


*Figure 2. Diagram from a recorder used for determining the coefficient of friction and boundary lubrication for 0.9 per cent NaCl (curve A) and for bovine synovial fluid (curve B). The measurement of the coefficient of friction is recorded, with intervals of 5 min, unloaded, until equilibrium values are obtained.*

with the slide (0.71), M is the total weight pressing the motion cylinder against the base plate (150), and $\lambda_1$ is the total amplitude in square units achieved by the calibration when the weight is placed first over the one pulley and then over the other (16). k is calculated to be 0.0145.

## MATERIAL AND METHODS

0.9 per cent NaCl and bovine synovial fluid (BSF) was used as a lubricant. The synovial fluid used in the experiments was from the hock joints of 2 year old heifers (The Danish Meat Trade School Roskilde). The fluid was taken in connection with slaughter and sterile precautions were exercised. Immediately after aspiration the fluid from the various joints was centrifuged for 20 min (3000 rev/min) and stored during the experimental period at 4° C. All measurements were carried out at room temperature (22° C).

To achieve boundary lubrication it is necessary to separate the rubbing surfaces for some minutes, thus making adsorption from the fluid possible. This was achieved by running each trial for 1 min loaded and 5 min soaking, then 1 min loaded and 5 min soaking until a constant value was obtained (Figure 2).

*Table 2 Effect of storage of synovial fluid at 4° C on coefficient of friction (μ)*

| Days after aspiration | Number of cases | Equilibrium μ |
|---|---|---|
| 0 | 10 | 0 0486 ± 0 0044 |
| 2 | 10 | 0 0515 ± 0 0044 |
| 14 | 10 | 0 0501 ± 0 0044 |
| 60 | 10 | 0 0870 ± 0 0068 |

## DISCUSSION

The most important function of the synovial fluid is to act partly as a nutrient and partly as a lubricant

Various theories about how the lubrication takes place have been advanced (Dowson 1967) Boundary lubrication (Charnley 1959) caused by adsorption of macromolecules from the synovial fluid on the cartilage surface depends on the composition of the synovial fluid as well as on the properties of the cartilage surface

By experiments with addition of enzymes (Wilkins 1968, Linn & Radin 1968) it was proven that boundary lubrication may be related to the protein component of the polysaccharide protein complex of the synovial fluid Addition of trypsin, which decomposes the protein, destroys the effect of boundary lubrication Experiments with trypsin in the present work confirmed this fact That boundary lubrication, in contrast to hydrodynamic lubrication, does not depend on the viscosity has been proven by admixture of hyaluronidase (Wilkins 1968)

In the design of the apparatus it was important to avoid the occurrence of hydrodynamic lubrication This was ensured partly by making the apparatus oscillating and partly by the use of a thrust bearing (McCutchen 1972)

In order to achieve boundary lubrication the rubbing surfaces must be separated for some time Owing to the macromolecules in the synovial fluid it takes some time before a state of equilibrium sets in In the present work equilibrium values with BSF occurred after 20 min which is a longer time than that demonstrated with the experiments with saline

In the present work the greatest emphasis was laid on standardization of the equipment The rubbing surfaces used were glass slides and thin rubber The condition of the rubber is decisive for the result (Sokoloff 1972) The trials proved that if the rubber were not cleaned sufficiently boundary lubrication either failed to materialize or was

The slides used were ordinary microscope slides which were cleaned in the following way. First in 4/5 of 70 per cent alcohol and 1/5 of concentrated hydrochloric acid; next washing with distilled water and drying for 90 min at 90° C.

The following trials with BSF were carried out:

1) 12 trials with the BSF from one joint with a new rubber every time preceded by a trial with saline in order to examine if the results were reproducible.
2) Examination of individual differences in boundary lubrication by BSF from 10 hock joints from sound animals of the same age.
3) Investigation of changes in boundary lubrication by BSF from 10 hock joints after storage at 4° C. The measurements were made immediately after aspiration, and after storage for 2 days, 2 weeks and 2 months, respectively.
4) Examination of the effect of an admixture of trypsin on boundary lubrication by BSF. Trypsin crystalline 7500–8000 BAEF units per mg (B.D.H. England) was used, 0.1 mg in 10 ml BSF in 10 min at 22° C.

## RESULTS

As is shown in Figure 3 the measurements with saline and BSF as lubricant show a decrease in the coefficient of friction during the test period as a demonstration of boundary lubrication, the decrease being most pronounced with BSF as lubricant. The diagram shows also that equilibrium $\mu$ occurred earlier when saline was used (after 10–15 min) than when BSF was used (after 20 min). The addition of trypsin to BSF showed unchanged $\mu$, pointing to the lack of boundary lubrication.

Table 1 shows the changes in $\mu$ when saline and BSF from the same and from different heifers were used as lubricants. As indicated in the table, the standard deviations in all three groups are low (below 0.0145 square units) thus being within the measurement error of the reading. The deviations were greatest in the group with BSF from different cases as lubricant.

Table 2 illustrates the changes in the lubricating effect during storage. As is shown in the table, it is not until after 2 months that a distinct change occurs in the form of a reduction of the lubricating effect as equilibrium $\mu$ shows a marked increase.

*Table 1. Effects on coefficient of friction ($\mu$) of boundary lubrication by saline and BSF*

| Lubricant | Number of tests | Initial $\mu$ | Equilibrium $\mu$ |
|---|---|---|---|
| 0.9 % NaCl | 12 | 0.1160 ± 0.0012 | 0.0787 ± 0.0012 |
| BSF same case | 12 | 0.2667 ± 0.0029 | 0.0399 ± 0.0015 |
| BSF different cases | 10 | 0.2770 ± 0.0044 | 0.0486 ± 0.0044 |

fluid are used as lubricant The greatest variations are caused by differences in the cleaning of the rubber and in its tension

On the basis of bovine synovial fluid from ten different hock joints investigations were made of individual variations and changes occurring during storage at 4° C The individual variations were found to be of no importance a decrease in the lubricating effect was observed only after storage for two months Addition of trypsin confirmed that boundary lubrication by synovial fluid can be related to the protein component

The conclusion is that the apparatus is considered suitable for clinical investigations of boundary lubrication in connection with different joint diseases

## ACKNOWLEDGEMENTS

The study was carried out with financial support from the Camp Foundation Michigan USA the Danish National Association against Rheumatic Diseases and the Society and Home for Cripples Copenhagen Denmark.

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decreased Furthermore changes in tension of the rubber altered the coefficient of friction To ensure constant conditions saline was consequently used as standard

In the experiments with BSF it was found in some cases that the amplitude at the beginning of a cycle of motion was lower than after sliding had been established This is in accordance with Linn (1967) who states that it is due to the fact that static friction is lower than dynamic

Swanson (1973) has mentioned that equilibrium $\mu$ with synovial fluid as lubricant is only a little lower than with saline He draws the conclusion that the function of the synovial fluid from a biomechanical point of view is to protect the cartilage against changes of the surface This is in conformity with Simon (1971) who found that tryptic digestions greatly reduce the wear protective properties of the synovial fluid

Linn (1968) found that the synovial fluid may be stored for a few days at 4° C without any changes occurring in the boundary lubrication This is in accordance with the findings in the present study in which changes occurring after storage for 0 2 14 and 60 days were investigated Not until after storage for 60 days was a distinct decrease of the lubricating effect observed

Individual variations in boundary lubrication when synovial fluid from the same kind of joints was used and the animals were healthy and of the same age could not be proven

The conclusion drawn from the experiments is that the apparatus can be regarded as suitable for demonstration of boundary lubrication by synovial fluid and that the results are sufficiently reproducible to be used for clinical studies of different joint diseases By combining the present examinations with measurements of the viscosity (Reimann et al in press) information may be derived about changes in the protein component as well as in the polysaccharide component of the synovial fluid

## SUMMARY

An account is given of an oscillatory rotating friction measurement apparatus which can be used for demonstration of boundary lubrication by synovial fluid when rubber and glass are employed as rubbing surfaces

A technical description of the apparatus is given

The greatest importance is placed on getting the apparatus to demonstrate reproducible results when saline and normal bovine synovial

Acta orthop scand 46, 11-24, 1975

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# AUTOGENOUS TRANSPLANTATION OF APOPHYSEAL CARTILAGE TO OSTEOCHONDRAL DEFECTS OF JOINTS

*An Evaluation of the Vitality by Means of Autoradiography ($^{35}$S)*

PÅL BENUM

Accepted 21 x 74

An experimental investigation has been performed, using dogs, to determine the basic histological changes that take place in cartilage of traction epiphyses (apophyseal cartilage) following autogenous transplantation to osteochondral defects of joints, whereupon it is exposed to the same types of mechanical stimuli as the joint cartilage of pressure epiphyses The macroscopical and morphological findings have been reported elsewhere (Benum 1974) Morphologically the cartilage appeared to remain vital following the transplantation, except for some parts of the growth plate overlying the metaphyseal osseous part of the transplants and the central basal regions of the overlying cartilage These areas underwent necrosis to varying extents The necrotic regions never extended into the cartilage superficially to the base level of the surrounding joint cartilage This cartilage was obviously sufficiently nourished by the synovial fluid Furthermore, the mechanical stimuli of joint function were found to prevent the ossification of the most superficial zone and contributed to the formation of a persisting and apparently vital cartilage that resembled true articular cartilage

The purpose of the autoradiographic study, which will be presented here, was to determine if the cartilage was also able to synthetize sulphur containing metabolites following injection of $^{35}$S labelled sulphate The application of this method as a functional test of the vitality of the transplanted cartilage also necessitated a study of the normal pattern of distribution of $^{35}$S within apophyseal cartilage

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Wilkins J F (1968) Proteolytic destruction of synovial boundary lubrication *Nature (Lond)* 219 1050 1051

*Key words* boundary lubrication, coefficient of friction, friction measurement lubrication, synovial fluid

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0.9 per cent NaCl to remove synovial fluid or blood containing radioactively labelled sulphate fixed for 24 hours in 4 per cent *formaldehyde solution buffered* with hexamethylene tetramin pH 7.4 decalcified with 7 per cent nitric acid for another 24 hours and then washed with water treated in ethanol xylene and finally *embedded in paraffin* 5-micron thick *sections* were cut from the same regions as the sections which were to be studied morphologically Following removal of the paraffin with xylene the mounted sections were passed down through ethanol to water Uncoloured *sections* were used for autoradiographic investigations applying the stripping film technique Kodak A R 10 was used and the time of exposure was 6 weeks

Following development of the autoradiographs which was performed in a Kodak D19b developer at 18° C for 4.5 minutes the *autoradiographs* were examined without staining Autoradiographs of sections from the femoral condyles of animals that had not been given any isotope served as *controls* No attempts were made to perform exact quantitative analyses of the concentration of the labelling *All autoradiographs that did not contain significant labelling corresponding* to the joint cartilage surrounding the transplant were discarded

## EXPERIMENTAL RESULTS

### *Iliac crest*

There was a marked concentration of granules corresponding to the cartilaginous portion of the iliac crest at all periods of observation The concentration of labelled sulphur was particularly high in the growth plate corresponding to the proliferating and hypertrophying cell layers

*Figure 2 Autoradiograph of cross section from the middle part of the iliac crest of a 4½ month old dog (× 10) A secondary centre of ossification has not appeared within this part of the iliac crest The labelling is particularly high corresponding to the position of the growth plate but there is a marked labelling corresponding to the overlying cartilage also*

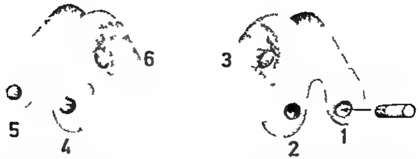


*Figure 1 The picture shows the position of the defects in both knees Defects nos 1 and 4 were filled with osseous transplants and devitalized cartilage or partially filled with pure osseous transplants Osteochondral transplants were implanted in the defects nos 2 and 5 and also in the defects nos 3 and 6 outside the cartilaginous joint surface*

## MATERIALS AND METHODS

Twenty of the 24 puppies used in the morphological study were used in the present investigation The details concerning the material operative procedure and preparation of specimens for the histological investigations have been presented elsewhere (Benum 1974) Here it should suffice to summarize that 4 mm wide cylindrical transplants consisting of apophyseal cartilage and adjacent metaphyseal bone removed from the iliac crest in 3 to 4 month old dogs before a secondary centre of ossification had appeared within the iliac crest were implanted into osteochondral defects of the femoral condyles In each animal one osteochondral fragment was implanted into a weightbearing area of the medial condyle of the left knee and one into a corresponding area of the lateral condyle of the right In 12 of the dogs similar transplants were implanted into a similar defect of the opposite femoral condyle of both knees but first after devitilization of the cartilage by heating at 50° C in sterile Ringers solution for 30 minutes Corresponding defects of the remaining 12 animals were partially filled with pure osseous transplants *Finally one osteochondral fragment was implanted into a defect outside the cartilaginous joint surface of the medial femoral condyle of both knees in all the puppies The locations of the defects and the various transplants are shown in* Figure 1 The animals were sacrificed at the following observation times 2 6 and 12 weeks 6 9 and 14 months giving the following numbers of transplants at each observation period eight osteochondral weightbearing transplants four weightbearing devitalized cartilage transplants four pure osseous transplants in weightbearing defects and eight non weightbearing osteochondral transplants Both at 6 weeks and 9 months however the transplants of only two of the four animals *could be prepared for* autoradiography for technical reasons giving only half the number of transplants available for autoradiography within the various groups at these observation times The pure osseous transplants were not studied autoradiographically

48 hours prior to sacrifice the animals were injected intravenously with 2 milliCi $^{35}S$/kg body weight as $Na_2{}^{35}SO_4$ diluted in 0 9 per cent *NaCl The* resected blocks containing the transplants and the specimens from the iliac crest were washed with

0.9 per cent NaCl to remove synovial fluid or blood containing radioactively labelled sulphate, fixed for 24 hours in 4 per cent formaldehyde solution buffered with *hexamethylene tetramin* pH 7.4, decalcified with 7 per cent nitric acid for another 24 hours and then washed with water, treated in ethanol, xylene and finally embedded in paraffin. 5 micron thick sections were cut from the same regions as the sections which were to be studied morphologically. Following removal of the paraffin with xylene the mounted sections were passed down through ethanol to water. Uncoloured sections were used for autoradiographic investigations, applying the stripping film technique. Kodak A.R. 10 was used and the time of exposure was 6 weeks.

Following development of the autoradiographs which was performed in a Kodak D.19b developer at 18° C for 4.5 minutes, the autoradiographs were examined without staining. Autoradiographs of sections from the femoral condyles of animals that had not been given any isotope served as controls. No attempts were made to perform exact quantitative analyses of the concentration of the labelling. All autoradiographs that did not contain significant labelling corresponding to the joint cartilage surrounding the transplant were discarded.

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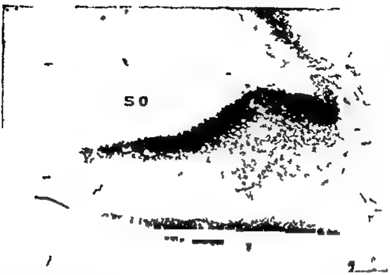


*Figure 3 A Autoradiograph of cross section from the posterior part of the same iliac crest as in Figure 2 A secondary centre of ossification has appeared within this part of the iliac crest (S O ) (×10) The labelling is very high corresponding to the growth plate (below) and the cartilage near the secondary centre of ossification (S O above) There is also significant labelling over the cartilage between these areas*

*Figure 3 B Detail from the growth plate shown in Figure 3 A (× 100) The labelling is concentrated over and around the cartilage cells of the growth plate but there is also some labelling over the overlying cells and over the matrix*

*Figure 3 C Detail from the cartilage adjacent to the secondary centre of ossification shown in Figure 3 A (× 100) The picture demonstrates a heavy labelling over and around the swollen cartilage cells (compare Figure 3 D) near the ossification centre There is also some labelling corresponding to the matrix between the cells*

*Figure 3 D Morphological detail from the same area as in Figure 3 C (Haemalun-azophloxine-saffron, × 100) The picture demonstrates markedly swollen cartilage cells near the ossification centre*

(Figures 2, 3, A and B, 4 A) In all regions of the apophysis the concentration of labelled sulphur was heaviest in and around the cartilage cells but *even the matrix between the cells* appeared to be labelled (Figures 3, B and C, 4 B) During the initial stage of the secondary *ossification of any segment of the iliac crest, a definitely increased* labelling was observed adjacent to the ossification centre corresponding to the regions where hypertrophic cartilage cells were demonstrated morphologically (*Figures 3, A, C* and D) As the ossicle increased in size and extended towards the growth plate, and as hypertrophic cartilage cells were no longer seen adjacent to the ossification centre by the morphological investigation, the cartilage in these regions no

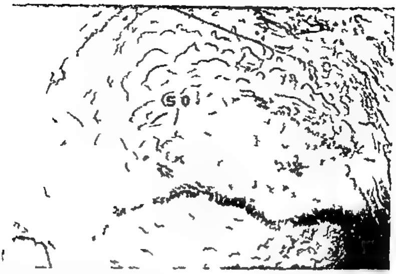


*Figure 4 A Autoradiograph of a cross section from the iliac crest of a 9½ month old dog during the advanced stage of secondary ossification (× 10) The labelling over the cartilage adjacent to the centre of secondary ossification (s o) is not significantly higher than over the cartilage of the central areas There is a heavy labelling corresponding to the growth plate*

longer seemed to contain larger amounts of labelled sulphur than the rest of the cartilage overlying the growth plate (Figure 4 A B and C)

## *Osteochondral transplants to the joint surface*

At all observation times the cartilage cells of regions which morphologically had appeared to be vital concentrated radioactively labelled sulphur The occurrence of granules was particularly abundant over and around the cells Corresponding to the regions which morphologically seemed to be necrotic only a few granules were seen and there was no tendency to concentration of granules around the cells (Figure 5) Thus the central parts of the growth plates and possibly some central parts of the overlying cartilage did not contain labelled sulphur in the 2 week specimens

At later observation times the unlabelled areas within the persisting unossified cartilage decreased in accordance with the reduction of the necrotic areas seen in the morphological study The concentration of granules over and around the cells was particularly high corresponding to the regions which morphologically contained a vital growth plate (Figure 5) This was also true over the regenerated parts of the growth plates In the most superficial zone corresponding to that part of the transplanted cartilage which was superficial to the base level of the

*Figure 4 B Detail from the area adjacent to the secondary centre of ossification shown in Figure 4 A (× 100) The labelling over the cells near the ossification centre is not significantly more pronounced than over the cartilage of the central areas There is a marked concentration of granules over and around the cells but there is also some labelling over the matrix*

*Figure 4 C Morphological detail from the same area as Figure 4 B (Haemalun azophloxine-saffron, × 100) The cells near the ossification centre are not significantly swollen compared to the other cartilage cells*

surrounding joint cartilage, concentrations of granules generally appeared over and around the cells in the autoradiographs at all periods of observation, even at the longest ones (Figures 6 and 7) As to the quantity of granules within this part of the cartilage no obvious changes were seen to take place during the study performed

Within the unlabelled regions heavily labelled islets were seen in some transplants These obviously represented the metaplastically formed cartilage found in the morphological study


*Figure 5 Autoradiograph of a section from a transplant to a load bearing defect Observation period 8 weeks (× 25) The major part of the cartilage is vital There is a lack of labelling only in a small region (n) in the basal area The labelling is particularly high over the cells of the growth plate*

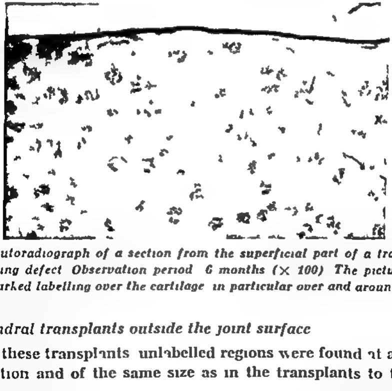

*Figure 6 Autoradiograph of a section from the superficial part of a transplant to a load bearing defect Observation period 6 months (× 100) The picture demonstrates a marked labelling over the cartilage in particular over and around the cells*

*Osteochondral transplants outside the joint surface*

Within these transplants unlabelled regions were found at about the same location and of the same size as in the transplants to the joint surface

These areas corresponded well to the areas which morphologically appeared to be necrotic Also in these transplants islets of tissue con

*Figure 7 Autoradiograph of a section from a transplant to a load bearing defect Observation period 14 months (× 100) There is heavy labelling over the cartilage in particular over and around the cells*

*Figure 8 Autoradiograph of a section from a transplant to a defect outside the joint surface Observation period 12 weeks (× 100) The labelling over and around the cells is clearly demonstrated*

taining a heavy concentration of labelled sulphur were occasionally seen within such regions The relation between the concentration of labelled sulphur within the morphologically vital superficial parts and that of the adjacent articular cartilage was definitely lower than in

the transplants to the joint surface However, the cells of these parts of the transplants also undoubtedly concentrated labelled sulphur (Figure 8).

*Osteochondral transplants with devitalized cartilage*

There was no significant concentration of granules either over the chondrocytes or over the matrix of the cartilage which was of apophyseal origin Corresponding to the ingrowing granulation tissue and to cartilage formed by metaplasia, however, there was a heavy concentration of granules, in particular over and around the most hypertrophic cartilage cells (Figure 9)

In all the autoradiographs some granules corresponding to the bone tissue were found especially over the superficial parts of the subchondral trabeculae, and also over the interspaces This labelling was, however, far less than that over the vital cartilage In the control autoradiographs from animals that had not been injected with $^{35}S$, no significant amounts of granules could be observed The background activity was low, both in these controls and in the autoradiographs from animals given the isotope

## DISCUSSION

Autoradiography using $^{35}S$ has been applied by several workers as a functional test of the vitality of cartilage cells (Wyburn & Bacsich 1955, Curran & Gibson 1956, Craigmyle 1958, Gibson et al 1958, Schatten et al 1958, De Palma et al 1963 and Hjertquist & Lemperg 1969) since Boström & Månsson (1952, 1953) found that the capability of cartilage to take up labelled sulphur and to incorporate it into chondroitin sulphate is dependent on an active enzymatic function of living *chondrocytes and since Dziewiatkowski (1951 a) had visualized such* uptake by autoradiographic technique

In the present study the cartilage devitalized prior to implantation did not contain any significant amounts of $^{35}S$ Furthermore, the labelling was mainly intra- and pericellular, whenever it occurred in joint cartilage, non-transplanted or transplanted apophyseal cartilage or metaplastically formed cartilage These findings should indicate that the uptake of $^{35}S$ was due to functional activity of the cells False *negative labelling of the transplants was eliminated by discarding* all sections where the adjacent joint cartilage was negative False positive autoradiographs are unlikely for reasons mentioned above and because all the controls were negative It has previously been shown that the

Figure 9 A Autoradiograph of a section from a control defect filled with osseous transplant and devitalized cartilage Observation period 6 weeks (× 10)

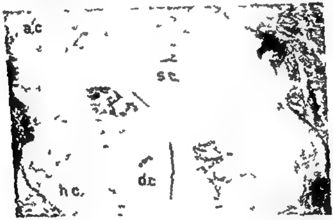


Figure 9 B Morphological detail from the middle part of the defect shown in Figure 9 A (× 25)

*The area of confluent labelling over the superficial part of the defect (Figure 9 A) reflects the radioactivity within the highly cellular and small-celled metaplastically formed cartilage (s c) shown in Figure 9 B The areas of unevenly distributed labelling to the left of and within the pale unlabelled area in the deeper region represent the metaplastically formed cartilage containing hypertrophic cells (h c) shown in Figure 9 B The pale unlabelled area of the autoradiograph corresponds to the remnants of devitalized cartilage (d c) in Figure 9 B (a c = articular cartilage)*

transfer of radioactively labelled sulphur compounds from the cells to the matrix starts even earlier than 48 hours after injection of the isotope

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*Figure 9 A Autoradiograph of a section from a control defect filled with osseous transplant and devitalized cartilage Observation period [illegible] weeks (× 10)*


*Figure 9 B Morphological detail from the middle part of the defect shown in Figure 9 A (× 25)*

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transfer of radioactively labelled sulphur compounds from the cells to the matrix starts even earlier than 48 hours after injection of the isotope

(Belanger 1954, Pelc & Glucksmann 1955) Hence, the present finding of considerable amounts of labelled sulphur in the matrix between the cells is most likely related to the length of the incubation period Since most of the sulphur incorporated into cartilage is present in chondroitin sulphate (Dziewiatkowski 1951 b, Boström 1952) and the in organic bound sulphur is removed by fixation in formalin (Campo & Dziewiatkowski 1961, Dziewiatkowski 1962) it seems reasonable to assume that most of the labelling in the cartilage in the present study is due to labelled sulphur incorporated into chondroitin sulphate

The distribution of the labelling in the non-transplanted apophyseal cartilage was found to be similar to that registered in pressure epiphyses (Dziewiatkowski 1951 a), the labelling being most concentrated at or near the junction of the cartilage with the metaphysis and in the area surrounding the secondary centre of ossification An increased concentration of labelled sulphur within the latter region was, however, no longer found when the initial stage of the secondary ossification had passed and hypertrophic cells were no longer seen Thus a great part of the cartilage was ossified without the presence of increased concentrations of labelled sulphuric compounds This may suggest that the mechanism of preparation of the cartilaginous matrix for ossification had been altered from the early stages, since chondroitin sulphate is assumed to play a role in the determination of the calcifiability of the matrix (Herring 1972)

The investigation of the transplanted apophyseal cartilage confirms the findings of the morphological part of the study that apophyseal cartilage, except for some basal parts adjacent to the metaphyseal osseous part of the transplants, survives transplantation to osteochondral defects of joints, and under the given circumstances, also *to the defects outside the cartilaginous joint surface* *It further* provides evidence that the cartilage cells do not only survive but also preserve their capacity for producing sulphuric compounds which are secreted into the matrix Considering that these compounds most likely are mucopolysaccharides, mainly chondroitin sulphate, the importance of this observation is obvious if transplantation of apophyseal cartilage should be applied in restoring joint defects The findings also showed that in particular the cartilage cells of the surviving parts of the growth plates, and growth plates which regenerated later on, produced heavy amounts of sulphuric compounds in a similar manner to the cartilage cells of the growth plates prior to transplantation Finally, cartilage formed metaplastically within necrotic cartilage was found able to produce similar compounds

## SUMMARY

$^{35}S$ was administered to 20 puppies which had been exposed to transplantation of osteochondral apophyseal transplants from the iliac crest to defects of the femoral condyles. Some transplants were implanted into defects within the joint surfaces whereas others were implanted outside the joint surfaces. An autoradiographic study was performed to assess the functional vitality of the transplanted cartilage at varying intervals up to 14 months. This study further necessitated an investigation of the normal pattern of incorporation of $^{35}S$ in the iliac crest.

The studies revealed that the incorporation of $^{35}S$ within the apophysis of the iliac crest was similar to that seen within pressure epiphyses, being heaviest in the proliferating and hypertrophying cells in the growth plate and around the secondary centre of ossification. The increased turnover of sulphur around the secondary centre of ossification declined, however, when the initial stage of the ossification was passed and when hypertrophy of cartilage cells was no longer seen. Ossification then took place without intensified production of organic sulphur containing compounds in this region.

The study further showed that apophyseal cartilage was still able to incorporate $^{35}S$ following transplantation to the mentioned defects, except in some basal central areas adjacent to the metaphyseal bone. These findings suggested that the cartilage not only survived, but also preserved its capacity for synthetizing sulphur-containing compounds, probably chondroitin sulphate.



## ACKNOWLEDGEMENTS

The author appreciates the technical help of Associate Professor Arne Attramadal M.D. and Mrs. Marit Johanson, Institute of Pathology, Rikshospitalet, Oslo. Financial support was received from The Norwegian Research Council for Science and the Humanities.


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Acta orthop. scand. 46, 25–30, 1975

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# EFFECT OF CORTISONE AND AN ANABOLIC STEROID UPON PLASMA HYDROXYPROLINE DURING FRACTURE HEALING IN RABBITS

George Lyritis, Zeta Papadopoulou, Panayotis Nikiforidis,
Menelaos Batrinos & Dionysios Varonos

Accepted 19 viii 74

Administration of hormones, affecting bone metabolism, is followed by alteration in hydroxyproline circulation and excretion (Kowalewski 1965).

In fracture experiments hydroxyproline circulation and excretion has been found to increase (Klein 1966, Kowalewski & Yong 1967, Fizikas et al. 1969, Struck et al. 1970). However, to our knowledge, the influence of cortisone and anabolic steroids on circulating hydroxyproline during fracture healing has not been investigated, although existing evidence, based on histological studies, indicates that cortisone treatment retards repair (Hulth & Olerud 1964, Koskinen 1965), whereas anabolics promote this procedure or antagonize the action of cortisone (Kowalewski & Gort 1959).

This has prompted us to investigate the effect of cortisone and anabolics on hydroxyproline excretion during fracture healing.

## MATERIAL AND METHODS

Thirty two male rabbits, body weight ranging from 1950–2200 g and 7–8 weeks old, housed individually and fed the same kind of food, were used. Under general anaesthesia with sodium pentobarbital, the animals sustained an operative fracture of the middle of the left radius. The rabbits were then divided into four groups and treated as follows: 1) controls, no treatment; 2) treated with hydrocortisone (hydrocortisone sodium succinate [illegible] mg per kg body weight every day); 3) treated with an anabolic steroid (norandrolone-19 phenyl propionate, 5 mg per kg body weight intramuscularly) and 4) treated with hydrocortisone plus the anabolic steroid in the above dosages. Blood samples were taken by heart aspiration on day 3, 6, 9, 13, 16, 22, 25, 28, 33, 37, 43, 50 and 55 after the fracture. The amount of blood taken was

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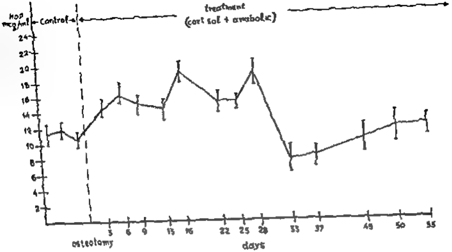


*Figure 2*

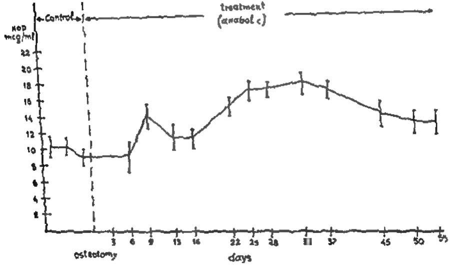


*Figure 3*

one on the 3rd and one on the 28th day after the fracture, the second being higher than the first (Figure 1) In the group of hydrocortisone treated animals a significant elevation of the HOP curve ($P < 0.01$) was noted from day 16, followed by a fall to low normal values, except for a small peak on about day 33 after the fracture (*Figure 2*) In the animals receiving the anabolic there was a sustained *increase* ($P < 0.01$)

2 ml The possibility of secondary anaemia was not taken into consideration Total plasma hydroxyproline (HOP) was measured using the method of Prockop & Underfriend (1960)

*Technique*

Initially, blood samples were drawn into 0I vol heparin (heparin sodium 1000 USP units per ml) The blood was centrifuged at 4° C for 30 minutes at 1000 × *g* and the plasma was separated Routinely the plasma proteins were precipitated immediately

*Procedure*

The procedure used for the assay of plasma HOP consists of precipitation of plasma proteins by cold ethanol, complete hydrolysis of the proteins by autoclaving overnight in alkali and measurement of HOP by the procedure of Prockop & Underfriend (1960)

The statistical analysis was carried out according to Student's t test

## RESULTS

The results are shown in Figures 1–4 It is to be noted that in all groups of measurements the standard deviation was narrow

In the group of animals serving as controls a statistically significant ($P < 0.01$) increase of plasma hydroxyproline was noted from day 3 to day 55 after the fracture The hydroxyproline curve showed two peaks,

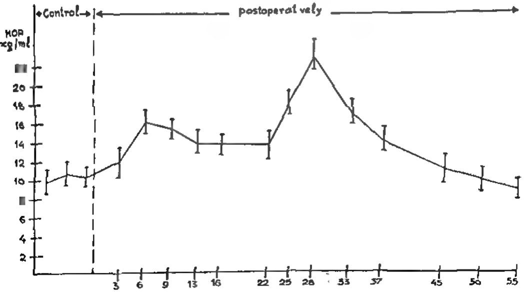


*Figure 1*

hydroxyproline found in control animals may be attributed to the degradation of bone and to a lesser degree to synchronous matrix formation in the area of fracture, and the second rise, at about the 28th day, to callus remodelling expected to be occurring at this time A similar phenomenon has been observed by Struck et al (1970)

The significant increase of plasma hydroxyproline during the first three weeks in cortisone-treated animals is most probably due to a massive collagen destruction at the site of the fracture and in other bones as well The retardation of callus maturation caused by cortisone (Sissons & Hadfield 1951) may be held responsible for the low hydroxyproline levels that follow the initial increase

The anticatabolic effect of the anabolic drug on osteolysis has been shown to inhibit the initial catabolic phase normally observed in fractures (Koskinen 1965, Kowalewski 1966) The increase of hydroxyproline after the second week may be explained by the increase of collagen synthesis due to a prolonged remodelling of the *primary callus*

It is interesting, however, that the protective influence of the anabolic steroid on bone catabolism manifested *immediately after* the fracture was almost abolished when cortisone was simultaneously administered at the dose used in the present study

## SUMMARY

The effect of cortisone and an anabolic steroid on plasma hydroxyproline (HOP) was investigated in young male rabbits, following operative fracture of the *radius* The action of these hormones was studied in [illegible]

[illegible] every other day) and a cortisone plus anabolic treated group [illegible]

[illegible] and during callus remodelling Cortisone produced elevation of HOP level *during the first* two weeks followed by a decrease to low normal values Animals treated with the anabolic did not present the initial rise but a sustained increase during callus remodelling When both the anabolic and cortisone were administered, a curve similar to that of cortisone-treated animals was obtained The initial increase of HOP is attributed to bone destruction and to a lesser degree to synchronous bone formation at the site of the fracture This catabolic process seems to be enhanced by cortisone and inhibited by the anabolic When, however, *the two* hormones are given together the protective anticatabolic effect of the anabolic is almost abolished

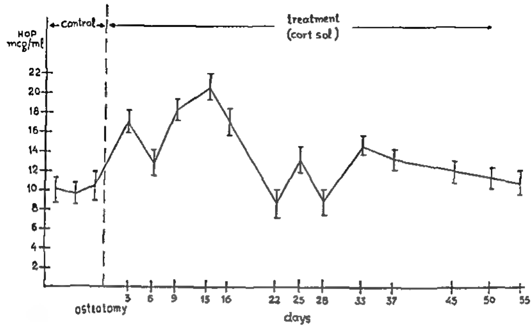


*Figure 4*

of HOP starting from the 9th day after the administration of the drug and lasting throughout the experiment (Figure 3)

In the group of animals which received both hormones, a curve similar to that of the hydrocortisone-treated animals was obtained HOP values were high during the first four weeks and decreased suddenly thereafter to lower than normal values (Figure 4) Both changes were statistically significant ($P < 0\ 01$)

## DISCUSSION

An increase of hydroxyproline in plasma and urine is found when bone collagen is destroyed but can also be noticed in cases of intense collagen synthesis (Laitinen 1967, Prockop & Kivirikko 1967). Elevation of hydroxyproline values is also found in urine (Klein 1966) and serum (Struck et al 1970) of normal animals with fractures

Corticosteroids have been found to decrease free and total hydroxyproline while the protein-bound fraction remains unchanged (Kibrick & Milhorat 1969) Anabolic steroids, on the other hand, have an antagonizing effect on the action of corticosteroids, probably through the promotion of collagen synthesis (Kowalewski 1966)

The process of fracture healing involves both destruction and synthesis of bone in a sequence of events which may result in fluctuations of plasma hydroxyproline In this respect, the early peak of plasma

hydroxyproline found in control animals may be attributed to the degradation of bone and to a lesser degree to synchronous matrix formation in the area of fracture, and the second rise, at about the 28th day, to callus remodelling expected to be occurring at this time A similar phenomenon has been observed by Struck et al (1970)

The significant increase of plasma hydroxyproline during the first three weeks in cortisone treated animals is most probably due to a massive collagen destruction at the site of the fracture and in other bones as well The retardation of callus maturation caused by cortisone (Sissons & Hadfield 1951) may be held responsible for the low hydroxyproline levels that follow the initial increase

The anticatabolic effect of the anabolic drug on osteolysis has been shown to inhibit the initial catabolic phase normally observed in fractures (Koskinen 1965, Kowalewski 1966) The increase of hydroxyproline after the second week may be explained by the increase of collagen synthesis due to a prolonged remodelling of the primary callus

It is interesting however, that the protective influence of the anabolic steroid on bone catabolism manifested immediately after the fracture was almost abolished when cortisone was simultaneously administered at the dose used in the present study

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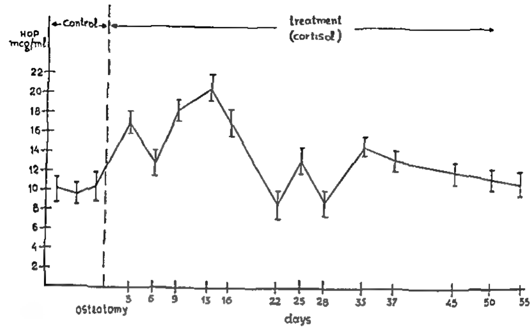
[illegible] kg every other day) and a cortisone plus anabolic treated group [illegible]

[illegible] of HOP level during the first two weeks followed by a decrease to low normal values Animals treated with the anabolic did not present the initial rise but a sustained increase during callus remodelling When both the anabolic and cortisone were administered a curve similar to that of cortisone treated animals was obtained The initial increase of HOP is attributed to bone destruction and to a lesser degree to synchronous bone formation at the site of the fracture This catabolic process seems to be enhanced by cortisone and inhibited by the anabolic. When however, the two hormones are given together the protective anticatabolic effect of the anabolic is almost abolished

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Acta orthop scand 46, 31–37, 1975

Martina Hansens Hospital, 1300 Sandvika Norway

# PHYSICAL WORK PERFORMED BY SURGEONS DURING ORTHOPAEDIC OPERATIONS

Paul Lereim & Johannes Rö

Accepted 8.ix 74

During an operation the surgeon performs physical work to a greater or lesser extent As far as we know the amount of this work load has not previously been determined By means of ergonomic methods we are able to estimate the oxygen uptake during the work, and then calculate the aerobic work as a percentage of the maximal aerobic capacity of the actual surgeon

Studies of this kind have been carried out on Norwegian fishermen (Nilsson 1970) and on workers in the steel industry (Nilsson et al 1970) The present study, carried out in Martina Hansens Hospital in the spring of 1970, included measurements of the oxygen uptake during work, body temperature, loss of water and variations in grip force

## MATERIAL AND METHODS

Four surgeons took part in the study Their physical characteristics are shown in Table 1 Their maximal aerobic capacity and oxygen uptake on submaximal work loads were analysed in the laboratories of the Institute of Work Physiology in Oslo

*Table 1 Physical characteristics of the test persons*

| Surgeon | Age | Weight kg | Max heart rate beats/min | Max oxygen uptake l/min | ml/kg min |
|---|---|---|---|---|---|
| A | 60 | 89 | 120 | 2.58 | [illegible] |
| B | 45 | 79 | 175 | 3.86 | 48 |
| C | 32 | 77 | 200 | 4.40 | 57 |
| D | [illegible] | 59 | 200 | 3.70 | 63 |

ACKNOWLEDGEMENTS

This work was carried out with the technical assistance of Miss I Gotsi The study was supported by a grant from the National Institute of Research, Greece

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*Key words* plasma hydroxyproline fracture healing

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the moment he entered the theatre, one recording being made every 5 minutes The transmitter is small, and does not disturb the surgeon during work

*Body Temperature*

Physical work leads to a rise in body temperature with extreme activity to more than 39° C The rectal temperature of the surgeons was measured pre- and postoperatively with a thermocouple mounted in a rubber tube

*Loss of Water*

Loss of water by sweating depends on room temperature and the individual tested Pre- and postoperative weight was noted, and the loss expressed in per cent of initial weight The scales used were accurate to ± 50 grams

*Grip Force* was recorded by means of electronic pressure transducers Pre- and postoperative values were noted and the difference expressed in per cent of the first value

## RESULTS

A typical heart rate curve recorded from a surgeon doing a Smith-Petersen arthroplasty is shown in Figure 2 The mean heart rate from each operation was calculated, and in the nomogram shown in Figure 1 the mean oxygen uptake was evaluated Table 2 shows the mean work load on each surgeon during different *operations expressed* in per cent of maximal aerobic capacity

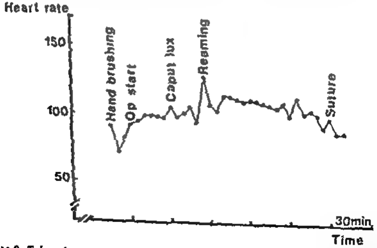


*Figure 2 Telemetric recorded heart rate of surgeon B performing a Smith Petersen arthroplasty Time difference between each registration = 5 minutes*

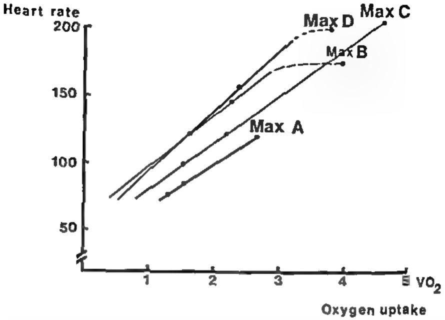


*Figure 1 The relationship between heart rate and oxygen uptake at increasing work loads is linear up to near maximum oxygen uptake (Max A B C-D) Oxygen uptake ($\dot{V}O_2$) is expressed in litre/min There is one line for each surgeon, and the two tests at submaximal work loads are marked with points at the graphs*

*Oxygen Uptake*

The maximal aerobic capacity of an individual is defined as the highest consumption of oxygen per time unit during maximal work within a short period of time (Hermansen & Saltin 1969) For this purpose the surgeons were tested on a bicycle ergometer (Monark) In addition to the bicycle test, two were also tested whilst running on a treadmill Oxygen uptake was determined by the Douglas bag technique The volume of the expired air was measured in a spirometer, and gas analyses were performed using the Scholander method for determination of its content of $O_2$, and $CO_2$ (Scholander 1947)

During activity the heart rate was recorded with a conventional electrocardiographic apparatus The signals were transmitted from the test persons by telemetry The cardiogram produced this way could be used in the evaluation of possible heart disorders

All persons were tested at two submaximal and at maximal work load on the same day One person was tested at 450 and 600 kpm/min, the remaining three at 600 and 900 kpm/min (kpm = kilopond meter 1 kp is the force acting on the mass of 1 kilogram for normal acceleration of gravity) The work periods were 6–8 minutes The expired air was collected during the last minute in two bags The heart rate was recorded continuously The relationship between heart rate and oxygen uptake is shown in Figure 1 a–d By recording heart rate during work it is possible from these graphs to estimate the oxygen uptake The actual oxygen uptake can be expressed as a percentage of the maximal oxygen uptake

During the operation the surgeon's heart rate was recorded telemetrically from

*Table 5 Variations in grip force of right and left hand compared with duration of the operation*

| Surgeon | Number of operations | Mean duration of the operation (min) | Increase or decrease of grip force Right (per cent) | Left (per cent) |
|---|---|---|---|---|
| A | 4 | 136 | −2 3 | −6 |
| B | 9 | 108 | −1 1 | −1 5 |
| C | 8 | 72 | −3.3 | +3 5 |
| D | 4 | 75 | −0 9 | +4 0 |

Table 5 shows the mean variations in force of the grip, compared with the mean duration of the operation The variations are small, but seem to show a tendency towards a diminished maximal force with increasing duration of the operation

## DISCUSSION

All surgeons who took part in this study had a relatively high maximal aerobic capacity according to Aastrand & Rodahl (1970) Two of the surgeons were practising physical exercise at least twice a week, the remaining two less frequently

Surgeon A had an extremely low maximal heart rate (120 beats/min), and in spite of repeated tests it is doubtful whether he had reached his maximal oxygen uptake Maximum oxygen uptake calculated from heart rate at submaximal work, however, showed an extremely good correlation with the values obtained from gas analyses

At rest and during minimal physical work psychological factors may influence the heart rate However, at the work loads described in this study these factors do not interfere with the increase in the heart rate caused by *the actual* work The method of recording the oxygen uptake by heart rate as described above has for many years been accepted and used in testing athletes (Aastrand & Roland 1970)

Nilsson (1970) found that *Norwegian fishermen* during *intermittent* work achieved 45 per cent of their maximal aerobic capacity Industrial workers, who *considered their* work to be too hard were [illegible] to be [illegible] on the [illegible] represented approximately 20 to 30 *per cent of* their maximum aerobic capacity, i e in about 90 per cent of all operations This work

*Table 2 Mean work load on the surgeon at each operation expressed in per cent of maximal oxygen uptake*

| Kind of operation | Surgeon A | Surgeon B | Surgeon C | Surgeon D |
|---|---|---|---|---|
| Arthrodesis | 29 | 31 | | |
| | [illegible] | 23 | | |
| | 22 | | | |
| Osteotomy | | 25 | 25 | 20 |
| | | 25 | | 20 |
| Operation for lumbar disc herniation | 29 | | 21 | |
| | | | 20 | |
| | | | 32 | |
| Menisectomy | | | 11 | 22 |
| | | | 21 | |
| | | | 19 | |
| Hip arthroplasty | | 26 | | |
| | | 31 | | |
| | | 41 | | |
| Various operations | | 27 | 14 | 22 |
| | | 23 | 20 | |
| | | 27 | | |

*Table 3 Mean increase of body temperature per hour*

| Surgeon | Increase |
|---|---|
| A | 0 15 ° C/hour |
| B | 0 40 ° C/hour |
| C | 0 33 ° C/hour |
| D | 0 37 ° C/hour |

*Table 4 Loss of water per cent of starting weight*

| Surgeon | Decrease |
|---|---|
| A | 0 16 per cent per hour |
| B | 0 28 per cent per hour |
| C | 0 07 per cent per hour |
| D | 0 07 per cent per hour |

There was an increase in body temperature during every operation Table 3 shows the mean increase per hour

Table 4 shows the mean decrease of body weight, reflecting the loss of water by sweating

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*Key words* physical work, surgeons, orthopaedic operations

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is performed by the large muscles in the arms, but also by the other muscles working statically to maintain the upright position

Saltin & Hermansen (1966) found that the temperature at all levels of exercise is set according to the relative work load of the individual and not to the absolute work performed Nielsen & Nielsen (1964) found a linear relationship between sweat rate and internal temperatures It is shown that a one per cent decrease of body weight due to loss of water might cause a ten per cent decrease of work capacity (Staff 1971)

The information obtained from this study indicates that the physical work performed by the surgeon during operations will often reach a level where good physical fitness is required Surgeons should therefore, for the benefit of their patients and themselves participate in regular physical exercise

During prolonged operations loss of body $H_2O$ should regularly be replaced


## SUMMARY

Four surgeons participated in a study which aimed to demonstrate the physical work load during operations Maximal oxygen uptake and maximum heart rate were determined by using the Douglas bag technique and recording the heart rate during the tests By working at two submaximal work loads heart rate was recorded and maximal oxygen uptake was determined indirectly

Using telemetry heart rate was recorded during operation and the mean oxygen uptake was determined In 90 per cent of all operations the surgeons were working at a level of 20 to 30 per cent of their maximal aerobic capacity

There was an increase in body temperature and a decrease of body weight after all operations In long lasting operations a decrease of grip force was noted


A preliminary report of this study was presented at the 37th Congress of the Scandinavian Orthopaedic Association in Uppsala Sweden June 13 1974

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due to the monomer in the acrylic cement, to the metabolites, to the large temperature rise during polymerization and to the method of implantation in the medullary cavity Up to this moment, however, an exact analysis of the possible causes of the various unfavourable side effects has not been made

Until now, little attention has been paid to the physical and mechanical properties of the various cements themselves, or to the meaning of these properties with respect to the functioning of the construction as a whole The purpose of this investigation is an attempt to fill in this gap in the information

For three of the most commonly used bone cements* we determined curing time and consistency as working properties of the uncured cement mixture water resorption, solubility and disintegration were selected to yield an impression of the physicochemical stability of these materials For comparison of mechanical properties, flexural strength and impact strength of the cured cements were measured Additionally we determined the influence of additives such as an antibiotic and radiopacifiers on these properties and the influence of porosity on flexural strength and impact strength

## MATERIALS AND METHODS

*Bone cements*

| | | |
|---|---|---|
| Simplex P | acrylic bone cement | radiopacifier added by manufacturer ($BaSO_4$) |
| Palacos R | acrylic bone cement | radiopacifier ($ZrO_2$) and pigments added by manufacturer |
| Palacos K | acrylic bone cement | no radiopacifier but with pigments |
| CMW | acrylic bone cement | no heterogeneous additives in powder as supplied |

Two packages $BaSO_4$ are delivered separately to be mixed with the cement by the operator

Our notation CMW – 0 no additives
CMW – 1, with 4 per cent $BaSO_4$ added
CMW – 2 with 8 per cent $BaSO_4$ added

Antibiotic Erythromycine lactobionate (Erythrocyne i v Abbott S A Belgium) added amount 4 2 per cent by weight

*Curing time*

A cylindrical cell made from heat insulating polyurethane foam was fitted with an Fe-Co thermocouple and filled with 0 5 ml of the cement mix Ambient

* Surgical Simplex (North Hill Plastics Ltd., London England)
Palakos (Kulzer & Co, Bad Homburg Germany)
CMW (CMW Laboratories Ltd., Blackpool England)

Acta orthop scand 46, 38-51, 1975

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# CHARACTERIZATION OF BONE CEMENTS

J R DE WIJN, T J J H SLOOFF & F C M DRIESSENS

Accepted 17.x 74

For the past twenty years bone cements, based on polymethylmethacrylate, have been used in orthopaedic surgery for the fixation of endoprostheses especially in cases of total hip replacement During this period a large number of papers have been published on the use of acrylic cement

From the beginning it has been clear that the cement itself and the method of intramedullary implantation have a distinct influence on the surrounding tissues and on various physiological functions of the body during or shortly after operation

As a result several clinical and experimental studies have been carried out regarding the unfavourable side effects of the acrylic cement, such as the development of allergy to the monomer, and to the inhibitors and catalysts, as well as their cytotoxic effects and the histopathological reactions in the surrounding cortical bone

In addition, much attention has been paid to the causes of physiological disorders such as a drop in blood pressure during implantation of the acrylic cement and fat embolism

Clinical follow-up studies of total hip replacements have been published dealing with postoperative complications such as infection, loosening of the prosthesis and loss of function Biomechanical investigations have been carried out with respect to the strength of the construction bone-prosthesis with and without fixation by acrylic cement and to the techniques and possibilities for obtaining an optimal bond between cement and bone

A final group of investigations to be mentioned here deals with measurements of the temperature rise and intramedullary pressure during implantation and hardening of the cement and with methods to keep this temperature down to an acceptable level

Generally there is agreement that all these untoward side effects are

$$E_b = \frac{P}{F} \frac{L^3}{4BD^3}$$

$E_b$ = flexural modulus of elasticity in $kg\,mm^{-2}$ P = load in kg F = deflection in mm L = the width of the span B = width of the specimen and D = thickness of the specimen

*Compressive strength and proportional limit*

Cylindrical test specimens were made by filling pre ision glass tubing having an inside diameter of 6 mm with the cement mix Non porous rods were obtained by curing the cement at 2 atm in a high pressure vessel From these rods specimens of 12 mm in length were sawn and the ends of the cylinders were ground flat and parallel to each other with 600 mesh grinding paper The test specimens were conditioned for 24 h in distilled water at 37° C and tested in compression at 22° C by means of an Instron testing machine

Compressive strength and proportional limit were determined at three different initial loading rates 1 5 $kg\,cm^{-2}\,s^{-1}$ 15 $kg\,cm^{-2}\,s^{-1}$ and 150 $kg\,cm^{-2}\,s^{-1}$

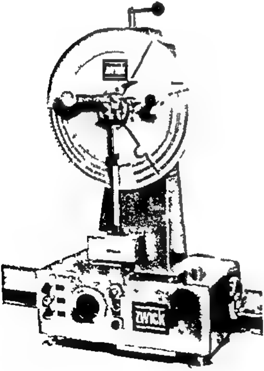


*Figure 1 The Dynstat apparatus for determination of flexural strength and impact strength*

temperature 22° C The thermocouple was coupled to a recording instrument the chart transport of which was activated when powder and liquid components of the cement were brought together The time from the start of mixing to the moment the temperature in the cell reached a maximum was taken as the curing time

*5-minute consistency*

A fixed amount of the cement was mixed at an ambient temperature of 22° C 4 min after the mixing was started 0 5 ml of the cement was placed on the centre of a glass plate (50×50×5 mm) by means of a gauged glass tube and covered with a second glass plate, 5 min after the mixing was started a weight was put on the centre of the top glass plate forcing the cement to slump out to a nearly round disc After the cement was cured under this load and between the glass plates the mean diameter of the disc was measured The weight that was necessary to produce a cement disc with a diameter of 25 ± 1 mm was taken as a measure of the consistency

*Water resorption, solubility and disintegration in water*

This test is a modification of a test prescribed by the American Dental Association for denture base polymers (A D A Specification no 12, Guide to Dental Materials and Devices, American Dental Association 1970–1971)

By means of a stainless steel mould, non porous discs with a diameter of 50 mm and a thickness of 0 5 mm were processed from the cement Immediately after hardening of the cement the discs were weighed (disc weight *a* mg) with a precision of 0 2 mg and immersed in distilled water of 37° C in preweighed flasks for 24 h (flask weight *b* mg) After this time the discs were removed from the water, wiped with a dry handtowel and weighed again (final disc weight *c* mg)

The water in which the cement had been immersed was carefully evaporated and the flasks were dried at 50° C to constant weight (final flask weight *d* mg) The weight increase of the cement disc (*c*–*a* mg) minus the weight of the flasks (*d*–*b* mg) gave the amount of water that had been absorbed by the cement The weight increase of the flasks after evaporation of the water measured the non volatile ingredients of the cement which were dissolved or disintegrated Finally the discs were dried to constant weight in a desiccator containing dry anhydrous calcium sulphate at 50° C (dried disc weight *e* mg)

The weight decrease caused by this treatment (*c*–*e* mg) is a measure of the total amount of volatile ingredients of the cement after water resorption

*Flexural modulus of elasticity*

For this test we used an apparatus as described by the American Dental Association for transverse deflection tests of denture base polymers (A D A Specification no 12) By means of a stainless steel mould the cement was processed to a non porous test specimen of 65×10×2 5 mm The specimen was conditioned in distilled water at 37° C for 24 h The deflection of the specimen caused by a load of 1000 g and to check for linearity also one of 2000 g was measured [illegible] seconds after loading The flexural modulus was calculated by means of the following expression

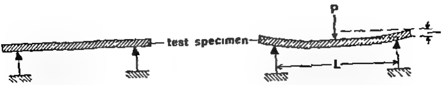


*Figure 2 Principle of bending test P = load F = resulting deflection, L = width of span*

antibiotic (4 2 per cent erythrocine lactobionate) seemed to enhance water resorption in CMW cement (1 6–1 8 per cent)

The amount of volatile contents appeared for all cements to lie between 1 9 and 2 3 per cent, while addition of an antibiotic raised this value to about 3 per cent

Solubility and disintegration were immesurably low for all cements tested except for the cements to which erythrocine was added In this case a solubility of 0 2 per cent per 24 h in distilled water of 37° C was found, which reflects, of course, the desired solubility of the antibiotic

*Flexural modulus of elasticity*

The principle of this bending test is shown in Figure 2 When the deflection of the specimen resulting from a load P is determined, a measure for the stiffness of the material can be calculated from

$$E_b = \frac{P}{F} \quad \frac{BD^3}{L^3}$$

$E_b$ being the modulus of elasticity (kg/mm²), P the applied load (kg), F the deflection (mm), B and D the width and thickness of the specimen, respectively (mm) This test did not reveal significant differences between the cements tested, all measurements were between 240 and 290 kg/mm²

*Compressive strength, proportional limit*

The compressive strength of a material is defined as the compressive stress (force per unit area) causing the material to break In the case of high molecular weight materials, such as bone cements, most mechanical properties are strongly dependent on the rate with which the material is loaded Under loading in compression it is likely that the polymeric material will not break (Figure 3 a) but instead will flow continuously beyond a certain maximum load (yield stress)

*Flexural strength and impact strength*

These measurements were made with a Dynstat apparatus (Zwick & Co Eisingen, Germany) according to DIN 51230, by means of which a four point flexural test (DIN 53452) as well as an impact test (DIN 53453) can be performed (Figure 1)

The dimensions of the test specimens were 15×10×2 mm · Specimens were conditioned for 24 h in distilled water at 37° C and all tests were carried out at 22° C ambient temperature

## RESULTS

### *Curing time*

The tested cements appeared to differ slightly in curing time as defined and measured in the manner described Simplex cement hardened in 12–13 min, Palacos R in 10–11 min and CMW cement in 6–8 min Radiopacifiers did not influence the curing time of CMW cement

### *Consistency*

As it is obviously not possible to determine the viscosity of a curing cement mix, it is common practice to take the "consistency" after a certain time as a measure for the workability of such a mix In this study the consistency is defined as the force necessary to slump out 0 5 ml cement mix between two glass plates to a disc with a mean diameter of 25 ± 1 mm The force was applied 5 min after the mixing was started, this time is an estimate of the time necessary for mixing of the components, waiting for dough formation, filling of a cement syringe (Slooff 1969), filling of the medullary cavity and introduction of the prosthesis

The results indicated that Simplex cement had the most fluid consistency after 5 min, the relevant force being about 200 gf Palacos R required 400 gf and CMW cement with 1200 to 1500 gf appeared to have the thickest consistency after 5 min Of course these results are closely related to the curing times of the various cements tested

### *Water resorption—solubility—disintegration*

The tested cements showed no difference or only slight differences with respect to these properties Water resorption percentages were 0 9 to 1 3 per cent for Simplex, Palacos R and CMW without radiopacifiers The addition of radiopacifier (8 per cent $BaSO_4$) resulted in a slight increase of the absorption of water (1 2–1 5 per cent), while adding an

or to carry out the determinations of mechanical properties over a certain range of loading rates In this presentation the last mentioned possibility has been chosen The values for proportional limit did not show significant differences for the cements tested The values were 350 ($\pm$ 50) kg/cm², 440 ($\pm$ 50) kg/cm² and 570 ($\pm$ 50) kg/cm² for loading rates of 1 5, 15 and 150 kg cm⁻² s⁻¹, respectively Table 1 shows the yield stresses found for the various cements

*Flexural strength, impact strength*

For the determination of flexural strength and impact strength methods were chosen according to DIN 53452 and DIN 53453, respectively, using a Dynstat apparatus according to DIN 51230 This method has been developed especially for the testing of polymeric materials Relatively small test specimens ($15 \times 10 \times 2$ or 3 mm) are used with this method, which is important for planned investigations concerning the testing of bone cements, which have been used in patients as fixation material The principles of these tests are drawn schematically in Figures 4 a and 4 b Specimens were obtained from plates which were processed from the cement under pressure and thus exhibited no porosity The results are shown in Table 2 Bone cement without any additives (CMW 0) has the highest values for both flexural strength and impact strength The availability of this pure form of acrylic cement facilitates the determination of the influence of heterogeneous additives such as $BaSO_4$ and antibiotics on these proper-

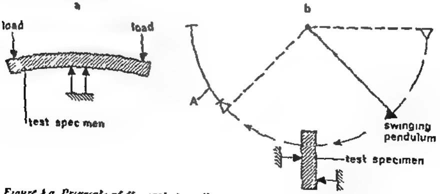


*Figure 4 a. Principle of flexural strength test the specimen is loaded until fracture occurs*

*Figure 4 b Principle of impact strength test arc length A is proportional to energy absorbed by breaking of the specimen*

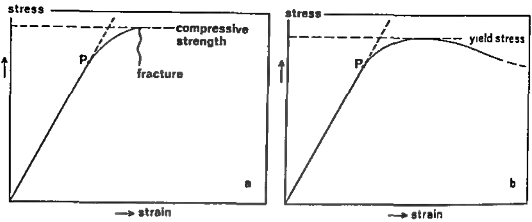


*Figure 3 a. Stress strain curve if (brittle) fracture occurs*

*Figure 3 b. Stress strain curve with plastic flow instead of fracture*
*P = proportional limit*

causing the stress-strain curve to pass through a maximum (Figure 3 b).

The linear part of the stress strain curve (low stresses, low strains) represents the elastic area, where the deformation resulting from the applied load is largely reversible. The non-linear part of the curve, beyond the point P in Figure 3 b (the proportional limit), represents the plastic deformation area, where deformation is largely irreversible. Thus when a material is loaded beyond its proportional limit, a permanent deformation will remain when the load is removed.

Consequently, if a material has a load-bearing function, both the proportional limit and the strength are important properties. Because of the dependence of compressive strength (yield stress) and proportional limit on the loading rate it is necessary, when comparing different materials, to keep loading rate constant in all measurements.

*Table 1. Yield stress ($kg\ cm^{-2}$) at different loading rates**

| Cement | Loading rate $kg\ cm^{-2}\ s^{-1}$ | | |
|---|---|---|---|
| | 1.5 | 15 | 150 |
| Simplex | 575 (± 25) | 750 (± 20) | 825 (± 35) |
| Palacos R | 560 (± 25) | 700 (± 32) | 840 (± 51) |
| CMW–0 | 650 (± 20) | 830 (± 41) | 1020 (± 42) |
| CMW–2 | 640 (± 21) | 790 (± 50) | 925 (± 31) |
| CMW–0 + 4.2 % erythrocyne | 640 (± 15) | 810 (± 10) | 1020 (± 25) |

* Values in parentheses represent the 95 per cent confidence interval of the mean.

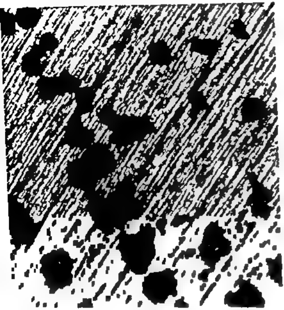

*Figure 5a Porosity pattern in bone cement (Palacos) cured under laboratory conditions at normal pressure (Magnification 80 ×, incident light)*

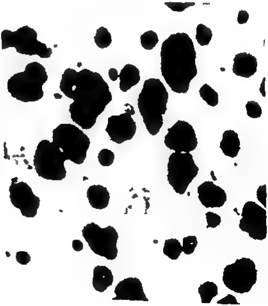

*Figure 5b Porosity pattern in bone cement (Palacos) as obtained from revision operation (Magnification 80 × incident light)*

*Table 2 Flexural strength and impact strength**

| Cement | Flexural strength (kg cm⁻²) | Impact strength (kg cm) |
|---|---|---|
| Simplex | 839 (± 15) | 3 4 (± 0 2) |
| Palacos R | 863 (± 15) | 4 1 (± 0 3) |
| Palacos K | 913 (± 25) | 3 9 (± 0 3) |
| CMW–0 | 1069 (± 39) | 5 9 (± 0 6) |
| CMW–1 | 819 (± 30) | 3 3 (± 0 5) |
| CMW–2 | 786 (± 24) | 2 8 (± 0 3) |
| CMW–0 + 4 2 % erythrocyne | 860 (± 22) | 4 7 (± 0 3) |
| CMW–2 + 4 2 % erythrocyne | 765 (± 17) | 3 8 (± 0 3) |

* Values in parentheses represent the 95 per cent confidence interval of the mean.

ties (resp CMW-1; CMW-2, CMW-0 + erythrocyne and CMW-2 + erythrocyne). From the results in Table 2 it follows that these additives decrease the values of flexural strength and impact strength to the level of the other cements which are premixed with radiopacifiers, such as $BaSO_4$ or $ZrO_2$ (Simplex, Palacos R) or even pigments only (Palacos K), by the manufacturer These results concern, as already mentioned, non-porous specimens, however, in clinical practice, the cement in the femur or acetabular cavity will be highly porous, due to the large temperature rise during hardening and to the clinical technique of mixing Therefore it is important to determine the influence of this porosity on mechanical properties

The processing of plate material (as used in the other experiments to obtain specimens) with a porosity that resembles the clinical situation appeared to be impossible In order to obtain a representative porosity, glass tubes with a square cross section (2×2 cm) were filled with the cement mix and immersed in water at 37° C until curing had taken place After curing, the cement rod was removed from the glass tube and test specimens were obtained by sawing the rod on a circular saw Microscopic examination showed the porosity pattern to be comparable with the porosity in a piece of cement that was obtained from material removed out of the femur of a patient who needed revision of a loosened hip posthesis Figures 5 a and 5 b, respectively) As these specimens could not be compared with the specimen obtained from plate material because of the different processing technique, a similar glass tube was filled with carefully mixed cement but in this case the cement was cured under two atmospheres air pressure in a

## DISCUSSION

In the non cured state, i e immediately after mixing of powder and liquid, the three bone cements tested showed specific differences in the values for curing time and consistency As mentioned before these handling properties are closely related and depend *inter alia* on the concentrations of initiators, accelerators and stabilizers These concentrations have been chosen by the manufacturer Other factors which will influence curing time, and thus consistency, are volume of the cement mix, powder to liquid ratio and ambient temperature, but these factors are, within practical limits, unlikely to even out the differences between the brands as revealed by our more standardized experiments Accordingly, each operator can determine which curing time and consistency suits him best It is likely, however, that too short a curing time and a too rapidly rising consistency will not be favourable for homogeneous filling of the femoral cavity The mechanical properties of the various cured bone cements do not appear to differ very much, at least not enough to base a preference for a specific brand thereon Besides that, the lack of information concerning the required minimum or optimum levels of mechanical properties of bone cements could only lead to a "the-stronger the better" philosophy, if there had been essential differences between the mechanical properties of the tested cements A marked phenomenon is the disadvantageous influence of heterogeneous additives such as radiopacifiers and antibiotics particularly on flexural strength and impact strength (Table 2) This could be an argument in the dispute about whether these additives are strictly necessary or not, if it were not for the deleterious effect of porosity on mechanical properties (Table 3) The overall effect of this porosity—which is inevitable with current cements and operating techniques—in combination with heterogeneous additives is a decrease of flexural strength and impact strength of about 50 per cent as compared to non porous cement without additives (CMW 0) Other reports (Lautenschlager 1973) show the same adverse effect of porosity on compressive strength and diametral tensile strength Porosity in bone cements is caused mainly by two factors the enclosure of air during mixing of powder and liquid and the volatility of the monomer and of water from body fluids with which the cement is contaminated during operation When the temperature in the cement rises during curing these low boiling point components will form more or less finely dispersed gas bubbles within the cement mass Due to the formation of gas bubbles and the thermal expansion of enclosed air

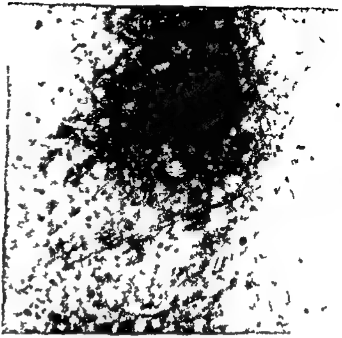

*Figure 5 c Bone cement cured under 2 atm pressure in laboratory (Magnification 80 × incident light)*

high pressure vessel The high pressure diminishes the volatility and in fact increases the boiling point of the monomer (100° C at normal pressure) so that the temperature rise during curing causes far less porosity (Figure 5 c) Specimens were obtained from this non porous rod in a similar way as in the case of the porous specimens Flexural strength and impact strength could now be compared and the results for some cements are presented in Table 3 These results clearly show the not unexpected negative influence of porosity on these mechanical properties to which the already noticed disadvantageous effect of heterogeneous additives is added

*Table 3 Influence of porosity on flexural strength and impact strength*

| Cement | Flexural strength (kg cm$^{-2}$) | Impact strength (kg cm) |
|---|---|---|
| CMW [illegible] (non porous) | 810 (± 65) | 3 9 (± 0 4) |
| CMW 0 (porous) | 579 (± 39) | 1 8 (± 0 2) |
| CMW 2+4 2 % erythrocyne (porous) | 356 (± 44) | 1 7 (± 0 3) |
| Palacos R (non porous) | 751 (+ 38) | 3 5 (± 0 3) |
| Palacos R (porous) | 442 (±100) | 2 5 (± 0 4) |

Values in parentheses are 95 per cent confidence intervals

## ACKNOWLEDGEMENTS

The authors are indebted to Mr P van Kesteren and Miss G Govers of the Institute of Dental Materials University of Nijmegen for carrying out the elaborate specimen preparations and testing procedures and to Miss I Keizer for typing the manuscript

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*Key words* acrylics bone cement methylmethacrylate acrylic bone cement cement endoprosthesis fixation

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the cement will expand 3–5 per cent by volume (Charnley 1970) Here we have a dilemma: this "foaming" effect will undoubtedly favour a good adaptation of the cement to the cavity wall, which is necessary for a stable fixation of the prosthesis On the other hand we see a dramatic decrease of mechanical properties due to the resultant porosity Within the framework of current clinical techniques it seems rather difficult to optimize for these tendencies which affect the quality of the arthroplasty in opposite directions It seems to be necessary for clinical techniques to be developed in which the porosity of the cement can be controlled

Again the need for information about the required level of relevant mechanical properties is felt The extensive literature concerning follow-up cases of total hip replacements does not reveal the extent or the frequency of mechanical failure of the cement in relation to, e g loosening of the prosthesis.

It is likely that the strength of the cement will play a role, but also that the proportional limit, flow properties and modulus of elasticity will have a definite influence on the stability of artificial joint constructions

## SUMMARY

Properties of acrylic bone cements during and after curing were determined for three brands of bone cement Curing time and consistency were chosen for the characterization of the handling and working behaviour of these materials The performance of bone cements after curing may be related amongst other things to the following properties water resorption, solubility/disintegration, flexural modulus of elasticity, yield stress, proportional limit, flexural strength and impact strength Methods to determine these handling and material properties are described

The influence of radiopacifying and antibiotic additives on these properties is evaluated as well as the influence of porosity on flexural strength and impact strength

The results indicate that considerable differences in the handling properties occur The material properties of the three brands tested do not show marked differences Radiopacifying and antibiotic additives appear to have a negative effect on material properties, the effect of porosity as it develops during curing under simulated clinical conditions is more pronounced

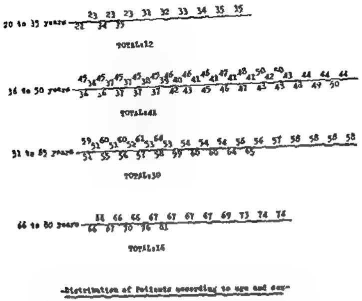


*Figure 1 Distribution of patients according to age and sex The figures represent the exact age of the patients expressed in years Figures above the line females Figures below the line males*

81 years There were 33 males and 77 females (Figure 1) The duration of the illness at the time of measurement varied from 3 months to 31 years Twelve per cent of this group of patients were under corticoid treatment

In the control group the ages varied between 20 and 71 years In this group there were 67 women and 33 men Of the two methods described by Loeb (1972) for the measurement of the mobility of the metacarpo phalangeal joints, the one that was used is a modification of the measurement method by mutual abduction of the joints at a flexion of 90° It is thought that this method gives more exact values for the degree of abnormal mobility and that it is a more exact indicator of the degree of articular laxity, due to normal or abnormal causes The mechanics of the apparatus used for these measurements is self evident (Figure 2) and its application is shown in Figure 3 In all cases the measurements were made, forcing the reciprocal abduction of the fingers by adding weights of 1 and 2 kg (Figure 2)

It was important when making the measurements, both in the affected group with rheumatoid arthritis as well as in the control group to keep in mind the ages of the patients and the duration of the illness this last parameter being a very important one for this study

## RESULTS

### *Patients affected by rheumatoid arthritis* (Figures 4 and 5)

*Group 1* In this series, only 26 patients had suffered from the illness for less than two years The exact duration of the illness is im-

Acta orthop scand 46, 52–60 1975

The Rheumatism Foundation Hospital, Heinola, Finland

# THE NORMAL AND PATHOLOGICAL MOBILITY OF THE METACARPO-PHALANGEAL JOINT

## *An Analysis of 100 Patients*

J E BELTRAN

Accepted 15 x 74

The mechanics of production of ulnar drift of the fingers in the course of rheumatoid arthritis is still under discussion However, the chain of events that finally leads to this deformity necessarily has to start at the level of the metacarpo-phalangeal joint

Already in a very early study of the illness, infiltrations of the structures that surround the metacarpo-phalangeal joint can be found

It is possible that capsular and ligamentous changes reduce joint stability much earlier than the appearance of bony or cartilaginous lesions (Brewerton 1957) Other causes of an exaggerated mobility of the metacarpo-phalangeal joints can be attributed to racial or geographic factors

A degree of abnormal mobility, whatever its origin, will affect the function of the hand and will therefore influence the election of a particular surgical procedure Consequently, we believe that the measurement of the mobility of the metacarpo-phalangeal joints can be of value not only at the moment of deciding on a certain surgical procedure, but also for the long-term study of the progressive deformities of the rheumatoid hand

## MATERIAL AND METHODS

Measurements were made between the third and fourth metacarpo phalangeal joints of the right hand of 100 patients admitted to the Rheumatism Foundation Hospital in Heinola, Finland from September to November 1973 Following the same scheme 100 patients not affected by rheumatoid arthritis admitted to the Accident and Plastic wards of the Ciudad Sanitaria Principes de España in Barcelona Spain were measured These latter results have been used as control material

The ages of the patients affected by rheumatoid arthritis varied between 21 and

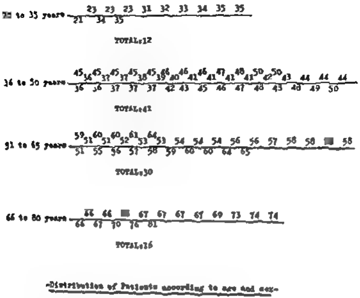


*Figure 1 Distribution of patients according to age and sex The figures represent the exact age of the patients expressed in years Figures above the line females Figures below the line males*

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## RESULTS

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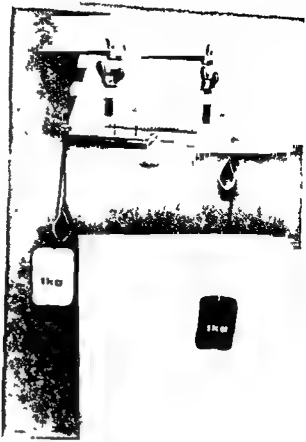
*Figure 2. The mutual abduction apparatus.*



possible to determine; therefore the date of onset has been taken as the date whereon each patient was diagnosed (criteria of A.R.A.) as having rheumatoid arthritis. The maximum and minimum measurements taken in this group were 30 and 10 degrees, respectively, whereas the majority gave an average result of 17 degrees of mutual abduction, when the weight used was 1 kg

However, using a double force the values obtained rose roughly proportionally. The minimum and maximum limits of this measurement were 15 and 35 degrees, respectively The average, however, rose from 17 degrees with a force of 1 kg to 20 degrees with a force of 2 kg.

*Group 2:* Forty-four patients had suffered from the illness for from 2 to [illegible] years.

In this group of patients, the forced abduction with a 1 kg weight gave 38 and 14 degrees as the absolute maximum and minimum values, the average value being 24 degrees

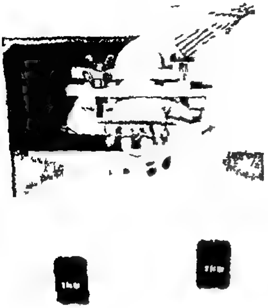


*Figure 3 The way the apparatus is used*

Raising the *force* to 2 kg the limit values rose from 24 to 45 degrees, average 34 5 *degrees*

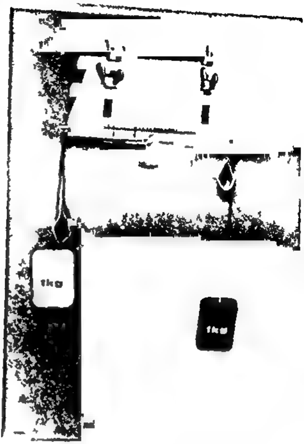
*Group 3* Thirty patients in this *series* belonged to this group They had suffered *from rheumatoid arthritis for more* than 6 years

The first measurement (1 kg) gave *some* limit values from 18 to 53 degrees whereas *the second* measurement (2 kg) gave minimum and maximum values from 26 to 52 degrees

*Control Group* (Figure 6)

*The* measurements obtained in the control *group* varied from 8 to 32 degrees In this group it was found *that* the age of the subject did not affect the degree of articular mobility However, this study seems to point out that females have a higher degree of articular mobility than males The measurements *made* on males gave a mobility arc from 8 to

*Figure 2 The mutual abduction apparatus*



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In this group of patients, the forced abduction with a 1 kg weight gave 38 and 14 degrees as the absolute maximum and minimum values, the average value being 24 degrees

FIRST GROUP
less than two years
(figures in months)

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7 | 6 | 5 | 20 | 21 | 14 | 3 | 7 | 6 | 24 | 20 | 20 | 18 | 23 | 21 |
| 12 | 10 | 6 | 20 | 19 | 13 | 11 | 24 | 21 | 11 | | | | | |

TOTAL =26

SECOND GROUP
from 2 to 6 years
(figures in years)

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 4 | 3 | 3 | 4 | 3 | 4 | 4 | 2 | 3 | 2 | 4 | 3 | 5 | 3 | 2 |
| 5 | 2 | 5 | 2 | 3 | 5 | 2 | 6 | 6 | 3 | 4 | 6 | 2 | 2 | 2 | 5 |
| 3 | 4 | 4 | 3 | 6 | 3 | 4 | 5 | 3 | 5 | 2 | 5 | | | | |

TOTAL=44

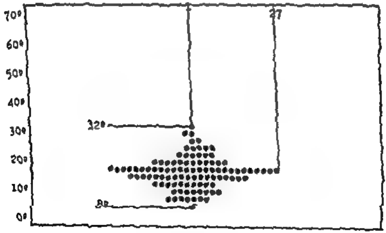
THIRD GROUP
more than 6 years
(figures in years)

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 20 | 19 | 24 | 31 | 7 | 9 | 10 | 10 | 11 | 14 | 15 | 18 | 7 | 6 | 9 | 12 |
| 38 | 24 | 36 | 6 | 8 | 17 | 20 | 29 | 16 | 11 | 19 | 29 | 30 | 6 | | |

TOTAL=30

Distribution of patients in groups according to duration of the disease

*Figure 5 The rheumatoid group subdivided into three sub groups according to the duration of the disease The exact duration of each case is represented in this table*




GROUP CONTROL
(100 PATIENTS)

*Figure 6 Maximum and minimum measurements obtained in a control, non rheumatoid group*

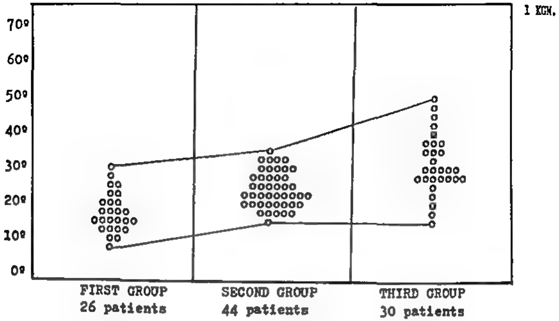



*Figure 4 a*

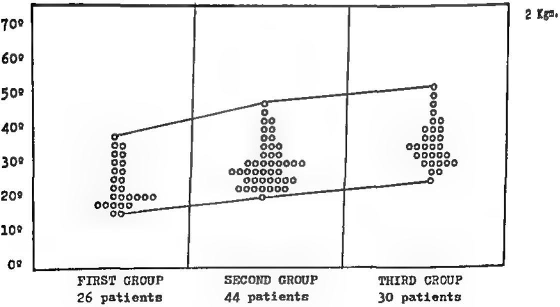



*Figure 4 b*

*Figure 4 Rheuma group Maximum and minimum measurements obtained applying 1 kg (a) nd 2 kg (b) weights in the three different groups (see text)*

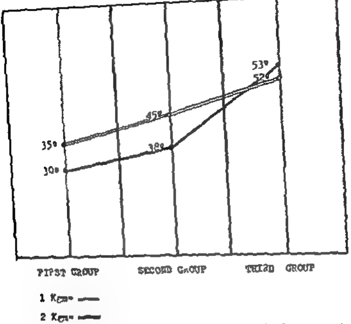



*Figure 7 Raising the force employed by 100 per cent higher proportional values were not obtained in the third group Note that the maximum value obtained applying 2 kg is less than the one obtained applying 1 kg*

it is difficult to understand why increasing the force in Group 3 did not result in higher values

This could be attributable to two factors In the first place, it is possible that a pathological joint gives without any pain under a certain amount of force However, when this level is surpassed in a group of patients who have suffered from rheumatoid arthritis for a long time and are therefore more likely to have developed structural joint changes, protective muscle reflexes which are difficult to eradicate start to act, blocking further movement of the joint Pain would trigger this blocking effect

In the second place, many of the metacarpo-phalangeal joints in the ... ld be the cause of a

... is possible that a long term series of measurements would confirm the clinical impression that patients who have an articular hyper mobility of the metacarpo-phalangeal joints before or at the beginning of the illness are more likely to suffer marked ulnar deviation of the fingers within a few years

26 degrees, whereas the same measurements on females gave a mobility arc that began at 12 degrees and reached its limit at 32 degrees

## DISCUSSION AND CONCLUSIONS

*Duration of the illness and its relationship with metacarpo-phalangeal joint hypermobility* (Figures 4, 5 and 6)

*In the first group (duration less than two years) it was found that* the values obtained were slightly higher than the limit values obtained in the control group; however, the majority of the patients of this group gave results which were compatible with the control ones No patient surpassed 32 degrees (control maximum), and only one reached 30 degrees Thus, it can be considered that this group has the same articular characteristics as those in normal people, perhaps with a statistical tendency towards joint laxity

In the group of patients included in the second group (duration of the illness from 2 to 6 years), and even more in those in the third group, it was found that the values obtained were statistically significantly above the normal, i e, in the second group the minimum value was 14 degrees (eight in the control group) and in the third 18 degrees The *maximum values are even more significant,* as the second group reached 38 degrees and the third group 53 degrees There is a tendency to consider that the values obtained in the three groups have a direct relationship with the duration of the illness Logically the most *destroyed joints must have some degree of greater mobility,* but in view of this study there seems to be little doubt that the joints of the patients affected by rheumatoid arthritis have a greater laxity the longer the disease has been present, even in patients with no local *involvement of the hand*

*Relationship between deforming forces and deformity* (Figure 7)

Raising the force employed by 100 per cent (i e, from 1 to 2 kg) would be expected to result in a proportional rise in the values obtained in the three groups, however, it was found that raising the weight by 100 per cent in the third group, did not give proportionally higher values In fact the maximum values obtained in the first measurement were hardly altered The maximum values *obtained in the first* measurement were higher than those in the second one

While it is easy to understand that lax structures will give to a greater extent, the greater the force applied to them (Groups 1 and 2),

Acta orthop scand 46 61–66 1975

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# LONG TERM OBSERVATIONS ON THE LOSS OF BONE MINERAL FOLLOWING COLLES' FRACTURE

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Accepted 23 iv 74

In a longitudinal study of the changes in bone mineral content in the forearm after fracture of the distal end of the radius (Colles' fracture) Westlin (1974) could demonstrate an average loss in the shafts of the fractured forearm of 18 per cent This change occurred during the first 4 months after the injury During the first year after the injury there was no tendency towards restoration of the lost mineral

There is no data available on long term observations of the bone mineral content after forearm fractures In order to find out if the loss of bone mineral after the fracture is permanent and irreversible it was decided to carry out a cross sectional retrospective study in women with Colles' fracture

## MATERIALS AND METHODS

Included in the study were 74 women age 61 8 ± 9 5*, who had sustained a fracture of the distal end of the radius—Colles fracture The time which had elapsed after the injury ranged from 1 month to about 11 years Only women in whom the fracture was the result of a trauma equal to or less than falling from the standing position were included. None of the women had a history of other fractures or of disease in the upper extremities Also in other respects these women were rated as healthy

The bone mineral content in the forearms was measured using the method of gamma absorptiometry (Nilsson & Westlin 1972 Westlin 1974) Rectilinear scans were made across both bones of the forearm 6 cm and 1 cm from the distal dorsal edge of the ulna (*Figure 1*) The bone mineral content was calculated and expressed in mg of bone mineral/cm² of the radius plus the ulna in the pathway of the beam In addition in some cases the thickness of the combined cortices of

Financial support was obtained from the Swedish Medical Research Council (Project no B73 17X 2737-05A)

* Average ± SD

## SUMMARY

The pathological mobility of the metacarpo-phalangeal joints of 100 patients affected by rheumatoid arthritis was studied, and the results were analysed and compared with the results obtained in a control non-rheumatoid group.

This report seems to suggest that rheumatoid metacarpo-phalangeal joints become more lax the longer the rheumatoid disease has been present. However, when there is marked local involvement of the joint this hyperlaxity cannot be proven because of pain and/or mechanical blockage.



## *ACKNOWLEDGEMENTS*

This report was made at the Rheumatism Foundation Hospital, Heinola Finland as part of a Doctoral Thesis. The author is grateful to Professor K Vainio for his help and stimulus He is also indebted to Dr. P. Raunio for valuable discussion and to the Workshop Department for their assistance in making the apparatus used for this study.



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*Key words* finger joints, measurement of mobility, rheumatoid arthritis


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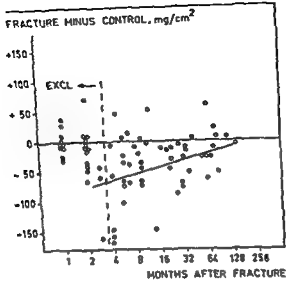



*Figure 2 The residual difference values for fracture minus those for uninjured forearm, in relation to time after the injury*

*Table 1 Bone mineral content of the forearms of women with Colles fracture (mg/cm², average ± SD)*

| | | Fracture | Uninjured | P* |
|---|---|---|---|---|
| Proximal | n = 50 | 414±65 | 453±84 | $P < 0.001$ |
| Distal | n = 48 | 274±63 | 226±76 | $P < 0.001$ |

* T test of pairs

of the fracture, the mineral content was about 20 per cent greater in the fractured arm

From the data of bone mineral content of the radius and the ulna on the proximal measuring site, presented in Figure 2, it can be seen that post traumatic osteoporosis expressed as the residual difference between the fractured and the uninjured forearms is still obvious in the group years after the injury There is, however, a tendency towards a decreasing residual difference which is significant ($r_{50} = 0.37$, $0.01 > P > 0.001$)

The variable of residual difference in cases observed 4 months and later after the fracture was also correlated to the age of the patient at the time of the fracture This relationship was not a rectilinear

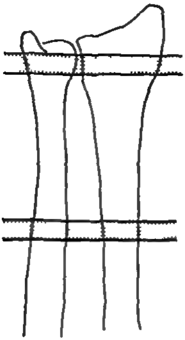


*Figure 1 Measuring sites*

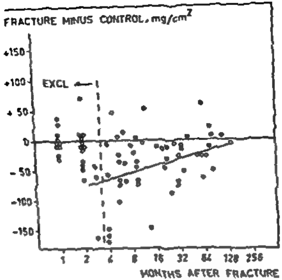
the radius and the ulna was calculated from the total widths and the widths of the marrow cavities of the two bones obtained from graphical tracings of the rectilinear scans of the proximal measuring sites (Westlin 1974)

The difference between the values obtained for the fractured and the uninjured side was calculated for both measuring sites and referred to as the *residual difference* Because of the skewed distribution of the variable of time after fracture the logarithm was used in order to adjust the data to least square statistics

## RESULTS

The parameter of post-traumatic osteoporosis, the residual difference, included a large scatter (Figure 2) The bone mineral content of the fractured arm as compared to the uninjured decreased during the first 4 months and then appeared to reach a minimum Also, it has previously been demonstrated that the post-traumatic loss increases during the first 4 months after fracture (Westlin 1974) Therefore, values obtained before 4 months were excluded leaving 50 cases observed from 4 months onwards for further calculations

There was a highly significant difference between the fractured and the uninjured forearms (Table 1) In the fractured arms the bone mineral content was reduced by about 9 per cent as compared to the uninjured arms, measured on the proximal site On the distal site, the site

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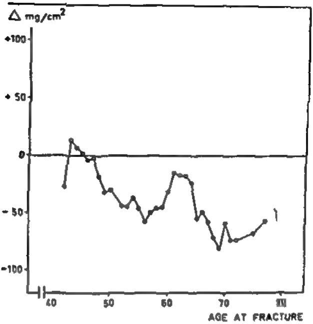


*Figure 3 The residual difference, values for fracture minus those for uninjured forearm, in relation to the age at the time of the fracture ( running average )*

one (Figure 3) It appears from these data that the peri- and early postmenopausal women are more vulnerable and loose more bone mineral after Colles' fracture Also, there is a tendency towards a greater than average loss also in the oldest age groups Interaction between age at the time of the measurement, age at fracture and time elapsed after fracture could not be demonstrated to be significant but it cannot be decided with certainty whether the apparent absence of post-traumatic osteoporosis before the age of 50 is due to restoration of lost mineral or to the fact that these women lost less in the first place

The combined cortical thickness was measured in both forearms in 15 cases [illegible] years or more after the fracture The thickness was 0 3 mm greater in the fractured arm without any significant or suggestive difference between the sides

## DISCUSSION

The major error in the data of the present study is introduced when the bone mineral content of the fractured forearm is related to that of the uninjured side It has previously been demonstrated that there is a considerable although non-systematic left-right variation of bone mineral content in the forearms (Nilsson & Westlin 1974)

In a longitudinal study Westlin (1974) failed to demonstrate any restoration of the bone mineral content within the first year following Colles fracture In other studies of post traumatic or other local osteoporosis covering many years after injury or onset of disease there has been little evidence of restoration of lost bone in adults (Nilsson 1966, Lundberg & Nilsson 1968, Nilsson & Westlin 1969) The findings of the present study seem to indicate that Colles' fracture in women unlike injuries or conditions with local osteoporosis previously studied is associated with a restoration of the lost mineral However, it should be kept in mind that the parameter of post traumatic osteoporosis in this study, the residual difference, is a result of changes in the fractured as well as in the uninjured limb We are unable to differentiate between these changes, the decrease of residual difference may be due to a more rapid change with time in the uninjured than in the injured forearm after fracture This limitation is inherent in a cross sectional study However, in a previous study it has been demonstrated that in the forearm loss of bone mineral is a constant finding after fracture (Westlin 1974) Therefore, the finding in certain age groups of this study of very little or no residual difference supports the hypothesis that a true restoration of bone mineral to the injured forearm may have taken place

The finding of a greater loss of bone mineral in women in the perimenopausal and early postmenopausal age groups is in agreement with the findings of Nilsson (1966)

Westlin (1974) demonstrated that the loss of bone mineral in the shafts of the forearm following Colles' fracture was not associated with thinning of the cortices of the bones In this study it is demonstrated that also later, two years or more after the fracture, the residual difference between the fractured and the uninjured sides cannot be explained by cortical thinning but is due rather to cortical porosity

## SUMMARY

Seventy four women were studied at various points in time between 1 month and 12 years after a fracture of the distal end of the radius—Colles fracture In 50 cases the maximum loss of bone after fracture was considered to have taken place in that more than 4 months had elapsed since the accident The bone mineral content was measured in both forearms with gamma absorptiometry It was demonstrated that the degree of post traumatic osteoporosis, calculated as the difference

between the values obtained for the injured and the uninjured arms, decreased with time The difference between the arms was greater in peri- and early postmenopausal and in very old women suggesting that these groups had lost more bone and/or been less able to restore lost mineral with time

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*Key words* bone mineral, gamma absorptiometry, fracture, osteoporosis

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Acta orthop scand 46 67–70 1975

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# DIPHTHEROID INFECTION OF THE CERVICAL SPINE

J H NEWMAN & R G MITCHELL

Accepted 15.x 74

The non sporing, non-motile, Gram-positive bacilli which form part of the normal flora of human skin and mucous membranes are collectively referred to as diphtheroids These organisms are frequently found to contaminate clinical specimens, such as blood cultures, but it is only relatively recently that pathogenic infections in man due to diphtheroid organisms have been reported For example, Johnson & Kaye (1970) have reported cases of bacterial endocarditis, meningitis, adenitis and hepatitis

Reports of diphtheroid organisms causing infections in bones or joints are rare Procek & Mlaya (1961) reported a diphtheroid osteomyelitis following a fracture, and Waitzkeh (1969) described a case of bone marrow infection due to *Corynebacterium acne*, which was considered to be unique Growth of diphtheroid organisms from rheumatoid joints has been reported (Duthie et al 1967), but their role as pathogens has not been established The purpose of this communication is to report a case of spinal osteomyelitis due to a diphtheroid organism, since this does not appear to have been described previously

## CASE REPORT

A 75 year-old author presented with one month s history of pain in his neck, which had gradually worsened and was beginning to radiate to his upper limbs and to restrict movement in his cervical spine

### *Examination*

The patient was afebrile and abnormal signs were restricted to his neck. Tenderness was elicited over the lower cervical spine, the movements of which were slightly restricted by pain There were no enlarged cervical glands and no abnormal neurological signs.

*Figure 1 Initial lateral X ray of the cervical spine showing narrowing of the C 5/6 disc space with bony destruction of both adjacent vertebrae and a soft tissue mass anteriorly*

### *Investigations*

Haemoglobin was 11 8 g/100 ml total white cell count 11 900/mm$^3$ and E S R 78 mm (Westergren) The following serological tests were negative or within normal limits Wassermann Gonococcal complement fixation test Widal agglutination to Brucella abortus antistaphylococcal haemolysin and antistreptococcal O titres and the Latex slide test The Mantoux reaction was negative Blood and urine cultures were sterile and no pathogens were isolated from a throat swab

X rays of the cervical spine showed marked narrowing of C 5/6 disc space with some destruction of both adjacent vertebral bodies A soft tissue mass was observed anteriorly (Figure 1) Bone scan showed increased uptake in the lower cervical spine

### *Progress*

The patient was treated with a cervical collar but developed a fever of 38 2° C The lesion in his neck was then aspirated under radiological control Altered blood was obtained from the lesion and this was subjected to bacteriological examination

### *Bacteriology*

The centrifuged deposit showed scanty clumps of filamentous branching Gram positive rods The deposit was cultured on horse blood agar plates both aerobically and anaerobically with added $CO_2$ and in cooked meat medium After seven days

*gure 2 After three months treatment the stroyed bone is being reformed*

incubation a scanty pure growth of tiny greyish white colonies was just visible on the anaerobic plate The organism was a pleomorphic, Gram positive rod non motile non sporing and non acid fast A positive Catalase reaction ruled out *Actinomyces sp* The diphtheroid grew more rapidly on repeated subculture, but remained an obligate anaerobe Its identity was finally established by gas chromatographic examination as a species of *Proprionbacterium* producing propionic and acetic acids from glucose The organism was sensitive to penicillin

*Treatment*

A Minerva plaster was applied and therapy with two grams daily of benzyl penicillin was started The patient s condition rapidly improved After six weeks the plaster was removed and a further X ray (Figure 2) showed evidence of healing His E.S.R was now 10 mm/hour Penicillin was continued for a total of 15 weeks and after discontinuing therapy there was no recurrence of symptoms or regression of radiological appearances

One year after presentation the patient was symptom free and had a normal range of movement in his cervical spine There was no radiological evidence of persistent infection and the affected vertebrae appeared to be fusing

## DISCUSSION

The diphtheroid organism isolated in this case was thought unlikely to be a commensal, since the organisms seen in the aspirate were too

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## DISCUSSION

The diphtheroid organism isolated in this case was thought unlikely to be a commensal since the organisms seen in the aspirate were too

numerous to have been transfixed during skin entry, no other skin commensals such as Staphylococcus albus were seen in the aspirate or isolated on culture, no other bacterial pathogen was isolated, and the infective process responded to penicillin, to which the diphtheroid was sensitive It therefore, seems that this case provides another example of a serious infection being caused by an organism which is not usually regarded as pathogenic


## SUMMARY

A unique case in which cervical osteomyelitis was caused by a diph theroid is reported and the previously recorded clinical infections due to similar organisms are briefly reviewed


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Duthie J J R Stewart S M Alexander W R N & Dayhaft R E (1967) Isolation of Diphtheroid organisms from rheumatoid synovial membranes and fluid *Lancet* i 142

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*Key words* · bacteria · diphtheroid osteomyelitis cervical spine infection


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# A STUDY OF HEIGHT, WEIGHT AND MENARCHE IN GIRLS WITH IDIOPATHIC STRUCTURAL SCOLIOSIS

STIG WILLNER

Accepted 8 ix 74

It has been established that the deformity in structural scoliosis tends to increase more during periods of rapid growth (James 1967) This fact appears to be unrelated to the etiology of scoliosis which is unknown in about 90 per cent of the cases (Cobb 1948) In addition it is known that deformity less than 60° usually does not increase after the cessation of growth Collis & Ponseti (1969), however, have shown that more severe thoracic and thoracolumbar scolioses tend to increase even in adult age, mostly due to secondary changes in the intervertebral discs It has previously been demonstrated (Willner 1974) that children with scoliosis are significantly taller than children without scoliosis, even if the shortening of the trunk caused by the deformity is disregarded and this was found in boys as well as in girls These observations were made on a heterogenous material of 1,616 children with structural or non structural scoliosis of varying degree and type The majority of the cases were mild About 25 per cent of the cases were structural and the remainder were cases of so-called functional scoliosis where the deformity could be completely reduced There were too few cases of severe scoliosis to permit comparison of growth patterns between mild and severe types

The object of the present study was to investigate height, weight and menarcheal age in a series of cases with definite idiopathic structural scoliosis and to compare the data between severe and mild cases and between girls with and without scoliosis

Financial support for this study was obtained from the Swedish Medical Research Council K69-23X 2737-01

This article was earlier published in Studentlitteratur Lund 1972

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*Key words* bacteria, diphtheroid, osteomyelitis, cervical spine, infection

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*Height*

The height was measured in the standing position The measured value was also corrected for the height reduction caused by the scoliosis according to the method of Bjure et al (1968) The degree of scoliosis estimated according to Cobb (1948) was used as a base value All the measurements were performed by the same investigator

*Weight*

The body weight was recorded at the time of admission in 196 girls who had been admitted to hospital

*Menarche*

The menarcheal age was recorded in girls admitted to hospital Of these the follow up time with regard to this variable (age < 15) was incomplete in 57 cases. Among the remainder data were missing in three leaving 137

The height and weight measures were recorded at the time of first examination In addition the height was studied longitudinally in the girls admitted

*Controls*

The heights were compared to the data of a series of girls without scoliosis described by Willner (1974) This latter series has been demonstrated to agree well with several contemporary height studies of children in Scandinavia and the data were collected during approximately the same period as those of the present study

Standard statistical methods were applied to the data and differences with a probability level of 95 per cent or better are referred to as significant.

## RESULTS

*Height*

The height corrected for the deformity, was significantly greater in girls with scoliosis than in the controls Also, in some age groups the uncorrected heights were increased above normal and on the whole, the growth curve of girls with scoliosis, even disregarding the shorten-

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growth appear to merge in adult age

The three ranks of severity $< 20°$, $20°–40°$, $> 40°$, all differed from the controls in their corrected height values but did not deviate from each other (Figure 2, and Table 4)

Girls with an early diagnosis of their deformity did not differ in height from the controls in most of the age groups but differed significantly from girls with a late diagnosis (Figure 3, Table 5)

## MATERIAL AND METHODS

Altogether 311 girls who had been treated in the Department of Orthopaedic Surgery of the Sahlgrenska Hospital in Gothenburg from 1963 to 1971 were included in the study The cases were drawn from the population of southern and western Sweden Only cases with unknown etiology and pathogenesis were included—idiopathic structural scoliosis

### *Severity of Deformity*

The cases were subdivided in three sets with regard to the severity of deformity $< 20°$, $20°$–$40°$ and $> 40°$ according to Cobb (1948) (Table 1)

*Table 1 Severity of scoliosis*

| | $< 20°$ | $20°$–$40°$ | $> 40°$ |
|---|---|---|---|
| No of cases | 114 | 65 | 132 |

Girls with a deformity exceeding 20° had been treated with the Milwaukee brace (Blount et al 1958) girls with a deformity of 50° or more had in most instances been operated on with internal fixation and spinal fusion according to Harrington (1962) The surgical procedure was modified by Nachemson with operation in two seances Both the latter groups had been admitted to hospital The remaining 114 girls had only been seen ambulatory and had not been treated

### *Age at Diagnosis*

The age at diagnosis was defined as the age at which the deformity was first noted usually before the child was seen in the Orthopaedic Department The age-distribution at the time of diagnosis (girls admitted) is demonstrated in Table 2 The cases were also subdivided into two groups according to the age at the time of diagnosis before the age of 10—*early diagnosis* (32 girls) after the age of 10—*late diagnosis* (165 girls) The age limit was chosen to separate the cases diagnosed before and after the prepuberal growth The older of the two subsets may be referred to as suffering from adolescent idiopathic scoliosis (Goldstein et al Scoliosis Research Society 1969)

*Table 2 Age at diagnosis*

| | $< 4$ | 4 | 5 | 6 | 7 | 8 | [illegible] | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No of cases | 2 | 1 | 1 | 5 | [illegible] | 10 | 7 | 13 | 28 | 39 | 41 | [illegible] | 14 |

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Girls with a deformity exceeding 20° had been treated with the Milwaukee brace (Blount et al 1958); girls with a deformity of 50° or more had in most instances been operated on with internal fixation and spinal fusion according to Harrington (1962). The surgical procedure was modified by Nachemson with operation in two seances. Both the latter groups had been admitted to hospital. The remaining 114 girls had only been seen ambulatory and had not been treated.

### *Age at Diagnosis*

The age at diagnosis was defined as the age at which the deformity was first noted, usually before the child was seen in the Orthopaedic Department. The age-distribution at the time of diagnosis (girls admitted) is demonstrated in Table 2. The cases were also subdivided into two groups according to the age at the time of diagnosis: before the age of 10—*early diagnosis* (32 girls), after the age of 10—*late diagnosis* (165 girls). The age limit was chosen to separate the cases diagnosed before and after the prepuberal growth. The older of the two subsets may be referred to as suffering from adolescent idiopathic scoliosis (Goldstein et al, Scoliosis Research Society 1969).

*Table 2 Age at diagnosis*

| | $< 4$ | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No of cases | 2 | 1 | 1 | 5 | [illegible] | 10 | 7 | 13 | 28 | 39 | 41 | 30 | 14 |

*Table 3 Comparison of height of girls with and without idiopathic scoliosis*

| Age | Height (cm) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Scoliosis | | | | | | | | |
| | Corrected | | | Uncorrected | | | Controls | | |
| | Mean | n | SD | Mean | n | SD | Mean | n | SD |
| 10 (9 5–10 5) | 143 0 | 7 | 4 6 | 139 0 | 7 | 9 9 | 138 9 | 110 | 5 5 |
| 11 – | 152 3 | 9 | 5 8 | 149 4 | 9 | 9 3 | 145 0 | 101 | 5 9 |
| 12 – | 158 3 | 24 | 7 7 | 155 6 | 24 | 8 1 | 152 3 | 102 | 5 8 |
| 13 – | 162 9 | [illegible] | 5 8 | 159 9 | 35 | 6 3 | 157 5 | 103 | 6 1 |
| 14 – | 166 3 | 40 | 6 7 | 163 9 | 40 | 8 9 | 160 6 | 100 | 5 0 |
| 15 – | 167 6 | 35 | 7 0 | 164 6 | 35 | 8 0 | 162 6 | 55 | 5 0 |
| 16 – | 168 6 | 31 | 4 4 | 165 4 | 31 | 4 7 | 163 7 | [illegible] | 4 9 |
| 17 – | 170 1 | 16 | 6 4 | 165 9 | 16 | 5 7 | | | |
| [illegible] – | | | | | | | 165 8 | 98 | 6 0 |
| 19 – | | | | | | | 165 7 | 57 | 6 1 |

*Table 4 Comparison of height between ranks of severity of scoliosis*

| Age | Height (cm) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Scoliosis | | | | | | | | |
| | < 20° | | | 20°–40° | | | > 40° | | |
| | Mean | n | SD | Mean | n | SD | Mean | n | SD |
| 10 (9 5–10 5) | 143 9 | 11 | 7 7 | 142 5 | 3 | 7 8 | 143 3 | 4 | 1 5 |
| 11 – | 147 6 | 16 | 9 2 | 153 6 | 3 | 7 1 | 151 7 | 6 | 5 6 |
| 12 | 157 5 | 14 | 8 4 | 159 5 | 11 | 6 0 | 157 3 | 13 | 9 0 |
| 13 – | 162 5 | 35 | 7 4 | 164 2 | 13 | 4 3 | 162 2 | 22 | 6 5 |
| 14 – | 167 2 | 45 | 5 7 | 166 3 | [illegible] | 5 5 | 166 2 | 32 | 7 0 |
| 15 | 167 4 | 45 | 5 9 | 167 6 | 12 | 7 0 | 166 7 | 23 | 7 6 |
| 16 – | 168 4 | 31 | 6 5 | 168 4 | 13 | 4 0 | 168 5 | [illegible] | 5 4 |
| 17 – | 169 6 | 12 | 6 6 | 168 6 | [illegible] | 2 7 | 170 6 | 14 | 6 5 |

The growth rate calculated as annual growth and based on longitudinal data from scoliosis (corrected height) and control girls indicate that although the girls with scoliosis were taller the growth rate after the age of 10 was less (Figure 4, and Table 6)

*Weight*

Data on weight for controls were not corrected for the purpose of the present study, and therefore the weights of the children with scoliosis

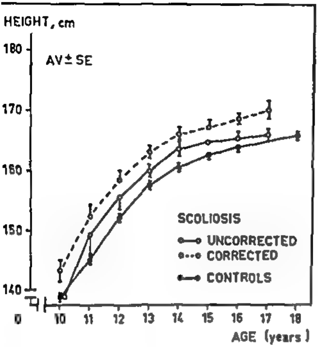


*Figure 1. Comparison of height of girls with and without idiopathic scoliosis*

*Figure 2 Comparison of height between ranks of severity of idiopathic scoliosis.*

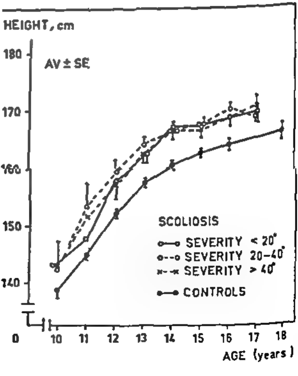

*Table 5 Comparison of height in scoliosis (corrected) with early and late diagnosis*

| Age | Height (cm) Diagnosis Early | | | Late | | |
|---|---|---|---|---|---|---|
| | Mean | n | SD | Mean | n | SD |
| 10 (9 5–10 5) | 141 2 | 5 | 4 8 | | | |
| 11 – | 148 3 | 10 | 6 0 | | | |
| 12 – | 153 7 | 11 | 8 3 | 159 6 | 19 | 6 3 |
| 13 – | 156 2 | 13 | 8 2 | 163 7 | 30 | 5 4 |
| 14 – | 160 6 | 7 | 7 3 | 166 6 | 38 | 6 7 |
| 15 – | 159 5 | 8 | 5 3 | 168 6 | 32 | 6 4 |
| 16 | 164 4 | 8 | 3 1 | 169 0 | 30 | 4 5 |
| 17 – | 165 8 | 5 | 3 3 | 170 1 | 16 | 6 4 |

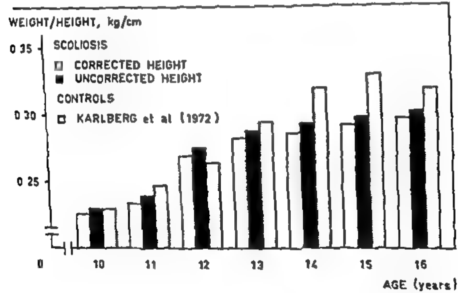


*Figure 4 Comparison of height gain per year of girls with and without scoliosis After the age of 15 no controls were available*

## DISCUSSION

Figure 4 shows that the growth rate was greater in the control cases than in the cases with scoliosis Nevertheless Figure 1 shows the scoliotic girls in all age groups to be taller than the controls This can

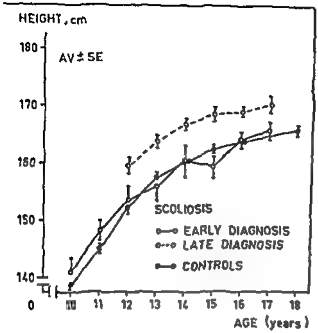


*Figure 3 Comparison of height in idiopathic scoliosis with early and late diagnosis*

were compared to data produced by Karlberg et al (1972) (Table 7, and Figure 5) In spite of the fact that the corrected height of the children with scoliosis exceeded that of the controls their weight was the same up to the age of 12 and later even less When their weight was related to a corrected height the difference became still more pronounced When corrected for height the difference in weight became even more obvious (Figure 6) in that children with scoliosis ceased to increase their weight much earlier than the control children The difference was significant

## *Menarche*

The age at menarche was 13 1±1 2* In Table 8 this value may be compared to available data on menarcheal age

The menarcheal age in girls with scoliosis cannot be demonstrated to deviate from that of the population at risk

However, in girls with a late onset of idiopathic scoliosis there was a significant positive relationship between the age at menarche and the age at the time of diagnosis (Figure 7) In girls with early onset too few were followed up to the age of menarche to permit calculations

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* Average ± standard deviation

*Table 5 Comparison of height in scoliosis (corrected) with early and late diagnosis*

| Age | Height (cm) Diagnosis Early Mean | n | SD | Late Mean | n | SD |
|---|---|---|---|---|---|---|
| 10 (9.5–10.5) | 141.2 | 5 | 4.8 | | | |
| 11 – | 148.3 | 10 | 6.0 | | | |
| 12 – | 153.7 | 11 | 8.3 | 159.6 | 19 | 6.3 |
| 13 | 156.2 | 13 | 8.2 | 163.7 | 30 | 5.4 |
| 14 – | 160.6 | 7 | 7.3 | 166.6 | 38 | 6.7 |
| 15 | 159.5 | 8 | 5.3 | 168.6 | [illegible] | 6.4 |
| 16 – | 164.4 | 8 | 3.1 | 169.0 | 30 | 4.5 |
| 17 | 165.8 | 5 | 3.3 | 170.1 | 16 | 6.4 |

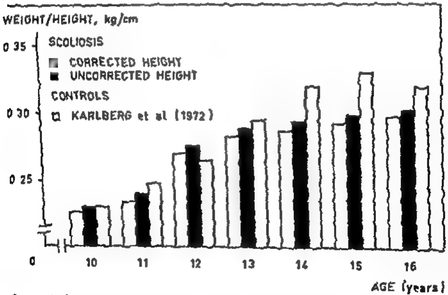



*Figure 4 Comparison of height gain per year of girls with and without scoliosis After the age of 15 no controls were available*

## DISCUSSION

Figure 4 shows that the growth rate was greater in the control cases than in the cases with scoliosis Nevertheless Figure 1 shows the scoliotic girls in all age groups to be taller than the controls This can

*Table [illegible] Comparison of growth rate of girls with idiopathic structural scoliosis and controls*

| Age (years) | Growth rate (cm/year) Girls Idiopathic scoliosis | | | | Controls | | | |
|---|---|---|---|---|---|---|---|---|
| | Mean | n | SD | SE | Mean | n | SD | SE |
| 10 | 5 7 | 6 | 3 2 | 1 3 | 6 3 | 100 | 2 1 | 0 2 |
| 11 | 5 6 | 15 | 2 6 | 0 7 | 7 0 | 100 | 2 1 | 0 2 |
| 12 | 4 6 | 24 | 1 7 | 0 3 | 5 5 | 100 | 2 1 | 0 2 |
| 13 | 2 6 | 44 | 1 6 | 0 2 | 3 2 | 95 | 2 0 | 0 2 |
| 14 | 1 7 | 57 | 1 7 | 0 2 | 1 6 | 70 | 1 4 | 0 2 |
| 15 | 0 8 | 61 | 1 0 | 0 1 | 1 1 | 47 | 1 1 | 0 2 |
| 16 | 0 5 | 51 | 0 8 | 0 1 | | | | |
| 17 | 0 1 | 39 | 0 3 | 0 1 | | | | |
| 18 | 0 | 6 | 0 | 0 | | | | |

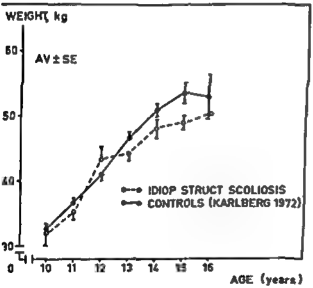



*Figure 5 Comparison of weight of girls with and without idiopathic scoliosis*

be explained by the previously demonstrated increase in growth rate before the age of 10 in children with scoliosis (Willner 1974)

The discovery that girls with scoliosis in spite of their deformity are not shorter than girls without scoliosis may be somewhat surprising considering the clinical experience that scoliosis in severe cases may render an individual very short However, if only the most extreme

*Table 7 Comparison of weight (kg) of girls with idiopathic structural scoliosis and non scoliotic controls (Karlberg 1972)*

| Age (years) | Weight (kg) | | | | | |
|---|---|---|---|---|---|---|
| | Scoliosis | | | Controls | | |
| | Mean | n | SD | Mean | n | SD |
| 10 (9 5–10 5) | 32 0 | 7 | 6 3 | 32 6 | 76 | 6 2 |
| 11 – | 35.3 | 9 | 4 5 | 36 7 | 78 | 6 9 |
| 12 – | 43 7 | 24 | 9 8 | 41 0 | 77 | 8 4 |
| 13 | 44 3 | 35 | 6 0 | 46 7 | 73 | 8.3 |
| 14 – | 48 4 | 40 | 9 3 | 51 0 | 75 | 8 3 |
| 15 – | [illegible] 4 | 35 | 6 7 | 53.8 | 16 | 7 4 |
| 16 – | 50 4 | 31 | 3 8 | 53 0 | 3 | 6 4 |
| 17 | 49 5 | 15 | 5 7 | | | |

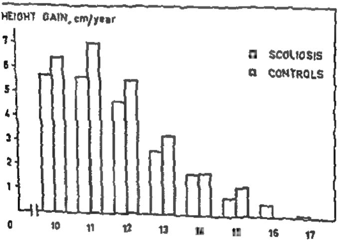



*Figure 6 Comparison of weight/height (kg/cm) of girls with and without scoliosis*

subset in the present study, children with a deformity of more than 40°, were studied, their average uncorrected height still was not less than that of the controls but rather the reverse (Figure 8)

The ...

sor ...

tre ...

Surgery does not influence the shape of the growth curves presented

*Table 8 Data on menarcheal age (Marshall & Tanner 1968)*

| | | Age at menarche |
|---|---|---|
| Denmark | 1963 | 13 1 ± 0 12 |
| Poland (Warsaw) | 1965 | 13 0 ± 0 04 |
| Australia (Melbourne) | 1966 | 13 2 ± 0 9 |
| USSR (Moscow) | 1965 | 13 0 |
| Italy (Florence) | 1960 | 12 5 ± 0 11 |

in Figures 1–3 which are based on measurements taken before any operative treatment had been applied

The longitudinal height study in girls with an early onset was, however, continued beyond the surgical treatment and in the comparison to girls with late onset, results may to some extent be influenced by disturbances resulting from surgery

The basic etiology of idiopathic structural scoliosis is unknown but a contributing factor appears in many of the cases to be a deviation from the normal growth pattern including an early growth spurt If the basic requirements were sufficiently penetrating, an additional requirement such as an abnormal growth pattern should not be needed and the body height should not deviate from that of the normal population

There seems to be a difference with regard to the presence of this

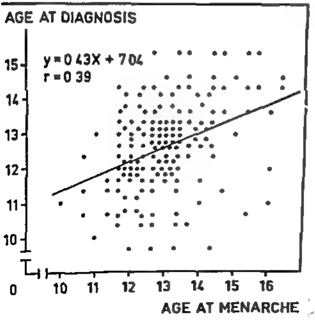
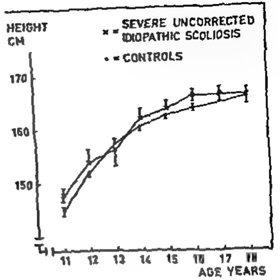



*Figure 7 The relationship of age at diagnosis and menarche in girls with scoliosis Girls with diagnosis before the age of 10 are excluded*

*Figure 8 Comparison of height between girls with uncorrected severe (> 40°) idiopathic scoliosis and girls without scoliosis*




abnormal growth pattern between adolescent idiopathic scoliosis and scoliosis with diagnosis before the age of 10

In the literature James (1967) among others has shown some differences between adolescent and infantile scoliosis One of these is the sex distribution Sixty per cent of the total occurrence of infantile scoliosis is in boys while 90 per cent of the total occurrence of adolescent scoliosis is in girls In adolescent scoliosis the proximal curve is usually convex to the right (90 per cent) while in infantile scoliosis the curvature is to the left (88 per cent) (James 1954, 1967) An additional difference between the two types of scoliosis can be found in the differences in mean average height demonstrated in the present study

Menarche may be used as a sign of maturity In the present study the age at menarche *per se* did not deviate from that of normal girls However within the group of girls with scoliosis a significant positive relationship could be demonstrated to exist between the age at diagnosis of the scoliosis and the age at menarche Therefore there seems to be a certain relationship between maturation and scoliosis not only with regard to the growth in height

The data of the present study in combination with the data of a previous study on the growth pattern in scoliosis (Willner 1974) indicate that children with scoliosis are taller than children without this

*Table 8 Data on menarcheal age (Marshall & Tanner 1968)*

| | | Age at menarche |
|---|---|---|
| Denmark | 1963 | 13 1 ± 0 12 |
| Poland (Warsaw) | 1965 | 13 0 ± 0 04 |
| Australia (Melbourne) | 1966 | 13 2 ± 0 9 |
| USSR (Moscow) | 1965 | 13 0 |
| Italy (Florence) | 1960 | 12 5 ± 0 11 |

in Figures 1–3 which are based on measurements taken before any operative treatment had been applied

The longitudinal height study in girls with an early onset was however, continued beyond the surgical treatment and in the comparison to girls with late onset, results may to some extent be influenced by disturbances resulting from surgery

The basic etiology of idiopathic structural scoliosis is unknown but a contributing factor appears in many of the cases to be a deviation from the normal growth pattern including an early growth spurt If the basic requirements were sufficiently penetrating an additional requirement such as an abnormal growth pattern should not be needed and the body height should not deviate from that of the normal population

There seems to be a difference with regard to the presence of this

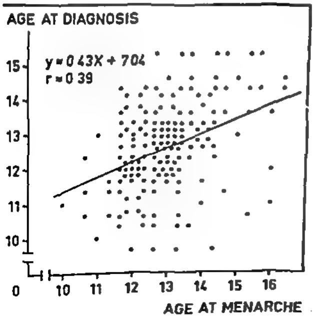



*Figure 7 The relationship of age at diagnosis and menarche in girls with scoliosis Girls with diagnosis before the age of 10 are excluded*

Marshall W A & Tanner J M (1968) Growth and physiological development during adolescence *Ann Rev Med* 19 283
Willner S (1974) Growth in height of children with scoliosis *Acta orthop scand* 45 854

*Key words* idiopathic scoliosis height weight menarche

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deformity As this conclusion is based on two separate independent series of observations which are being compared to four independent series of height studies in normal children it must be postulated that children with scoliosis in Sweden are taller than the average population

## SUMMARY

In a series of girls with idiopathic structural scoliosis the height weight and age at menarche were studied It was found that the girls were on the average taller than a control population and that except for the most severe cases their height was greater even if the trunk shortening caused by the deformity was not accounted for The girls with scoliosis were also somewhat leaner They did not deviate in age at menarche from normal girls in Sweden but there was a positive relationship between the age at diagnosis of the deformity and the age at menarche When assessed together with previous data on the subject of height in children with scoliosis in Sweden it must be concluded that children with this deformity have a growth pattern which deviates significantly from that of the normal population

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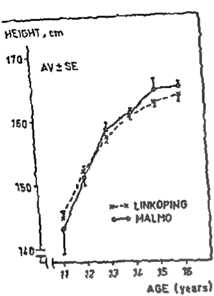


*Figure 1 Comparison between total heights in control girls in the present study and girls tested to be representative of the growth pattern in Sweden (Willner 1974)*

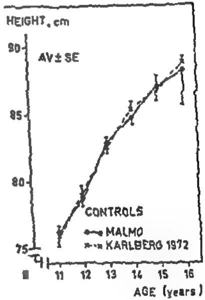


*Figure 2 Comparison of sitting heights of girls, comparing controls in the present study and data by Karlberg (1972)*

In the children previously sampled to serve as controls in studies of height (Willner 1974, 1975) only the height in standing was recorded For the purpose of the present study, therefore, 201 children, pupils in the schools of the city of Malmo, were measured The standing height of these children agreed well with the control children previously used (Figure 1) and, therefore, also with several other height studies of children in Scandinavia (Willner 1974) Furthermore the sitting height of the Malmö sample agrees well with the data obtained by Karlberg et al (1972) (Figure 2) Therefore it was felt that the body proportion of the scoliosis girls in Gothenburg and the normal girls in Malmö could be compared

All the girls scoliosis and controls, were measured not only in a standing but also in a sitting position with sitting height being the height of the trunk and the head measured with the girls sitting on a flat chair in an erect position and was defined as the distance from the surface of the seat of the chair to the top of the

Acta orthop scand 46, 84–89, 1975

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# THE PROPORTION OF LEGS TO TRUNK IN GIRLS WITH IDIOPATHIC STRUCTURAL SCOLIOSIS

STIG WILLNER

Accepted 8 ix 74

In previous studies it has been established (Willner 1974, 1975) that children with scoliosis are taller than average This could be demonstrated in boys as well as in girls and in functional as well as in structural scoliosis

In a study including girls only it could be demonstrated that cases of idiopathic adolescent structural scoliosis were taller than average even if the shortening caused by the deformity was not accounted for In contrast, girls with juvenile or infantile scoliosis did not deviate from the average in this respect

Although it is common knowledge that scoliosis is related to growth there are no previous observations of this difference in stature, nor are there any observations of body proportions in children with scoliosis

The objective of the present study was to find out whether the increase in height observed in children with scoliosis was general or confined to the spine thereby disturbing the body proportion in these children

## MATERIAL AND METHODS

The study included 164 girls with adolescent idiopathic scoliosis all confirmed radiographically, treated at the Department of Orthopaedic Surgery, Gothenburg during the years 1963–1971 These cases have been described previously (Willner 1975) The measurements of body height were obtained at the time of the first visit before any treatment had been given Only cases in whom the scoliosis exceeded 20° according to the measuring method of Cobb (1948) were included All the measurements were performed by the same investigator

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Financial support for this study was obtained from the Swedish Medical Research Council K69-23X-2737 01
Earlier published in Studentlitteratur, Lund 1972

*Table 2 Comparison of the ratio between the sitting height and the total height minus the sitting height in girls with idiopathic structural adolescent scoliosis and controls*

| | Sitting height/total height minus sitting height | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Scoliosis | | | | | | | | Controls | | | |
| e | *Corrected* | | | | *Uncorrected* | | | | | | | |
| | Mean | n | SD | SE | Mean | n | SD | SE | Mean | n | SD | SE |
| | 1 08 | 4 | 0 05 | 0 03 | 1 04 | 4 | 0 06 | 0 03 | 1 08 | 28 | 0 04 | 0 01 |
| | 10 9 | 19 | 0 06 | 0 01 | 1 06 | 19 | 0 05 | 0 01 | 1 08 | 27 | 0 05 | 0 01 |
| 3 | 1 10 | 30 | 0 06 | 0 01 | 1 08 | 30 | 0 12 | 0 02 | 1 10 | 44 | 0 04 | 0 01 |
| 4 | 1 09 | 33 | 0 06 | 0 01 | 1 06 | 33 | 0 07 | 0 01 | 1 12 | 35 | 0 05 | 0 01 |
| 5 | 1 10 | 32 | 0 06 | 0 01 | 1 07 | 32 | 0 06 | 0 01 | 1 12 | 17 | 0 03 | 0 01 |
| 6 | 1 13 | [illegible] | 0 05 | 0 01 | 1 09 | 26 | 0 05 | 0 01 | 1 14 | 50 | 0 05 | 0 01 |
| 7 | 1 11 | 15 | 0 07 | 0 02 | 1 09 | 15 | 0 07 | 0 02 | | | | |

## RESULTS

The sitting height corrected for the influence of the deformity was significantly greater in girls with scoliosis than in controls (Table 1 and Figure 3) The uncorrected heights were also greater than in the controls but only in young girls In the latter case the proportion, expressed as the ratio between the trunk and the height not accounted for by the trunk, differed in that the trunk contributed less to the total height in girls with scoliosis (Table 2) However, when the shortening was accounted for, the corrected ratios in girls with scoliosis and in the controls agreed well indicating that the increase in height was equally distributed between legs and spine

## DISCUSSION

The variable sitting height, used in the present study [illegible] the sum of the heights of the pelvis, the spine and the head Growth of the head may be neglected in that the annual growth between the ages of 8 and 17 in girls is no more than 0.2 centimetres (Simmons 1944) The pelvis contributes no more than about [illegible] per cent of the total sitting height (Anderson et al 1965) For the purpose of the present study, therefore, the sitting height may be regarded as a parameter of the length of the spine, and the difference between total height and sitting height as a parameter of leg length

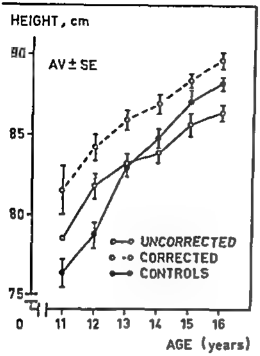


*Figure 3 Comparison of sitting heights of girls with idiopathic adolescent scoliosis and controls*

*Table 1 Comparison of sitting height in girls with idiopathic adolescent scoliosis and controls*

| Age years | Sitting height (cm) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Scoliosis | | | | | | Controls | | |
| | Corrected | | | Uncorrected | | | | | |
| | Mean | n | SD | Mean | n | SD | Mean | n | SD |
| 11 (10 5–11 5) | 81 5 | 4 | 3 1 | 78 5 | 4 | 3 5 | 76 3 | 28 | 4 6 |
| 12 – | 84.2 | 19 | 3 9 | 81 8 | 19 | 4 2 | 78 7 | 27 | 4 0 |
| 13 – | 85 9 | 30 | 2 9 | 83 2 | 30 | 3 3 | 82 9 | 44 | 3 6 |
| 14 – | 86 9 | 38 | 3 6 | 83 9 | 38 | 3 9 | 84 8 | 35 | 3 4 |
| 15 – | 88 3 | 32 | 3 0 | 85 6 | 32 | 3 7 | 87 0 | 17 | 3 4 |
| 16 – | 89 6 | 26 | 2 4 | 86 4 | 26 | 2 6 | 88 2 | 50 | 3 1 |
| 17 – | 89 5 | 15 | 3 2 | 85 3 | 16 | 3 4 | | | |

head of the child The sitting height was also corrected for the shortening of the spine caused by the scoliosis and in accordance with the method of Bjure et al (1968) For comparison between controls and scoliosis the sitting height and the ratio of the sitting height to the difference between the total height and the sitting height were used

Tupman G S (1962) A study of bone growth in normal children and its relationship to skeletal maturation *J Bone Jt Surg* 44 B 42

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Willner S (1975) A study of height weight and menarche in girls with idiopathic structural scoliosis *Acta orthop scand* (In press)

*Key words* idiopathic scoliosis proportion of leg to trunk

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Tupman (1962) and Tanner (1961) agreed that during adolescence the rate of growth was greater in the spine than in the legs and the findings of the present study support this concept in that with increasing age not only the controls but also the cases with scoliosis demonstrate an increasing sitting height in relation to the total height Duval-Beaupère (1970 and 1971) failed to demonstrate any deviation in total height or sitting height in children with scoliosis From previous studies it is known that, at least in Sweden, children with scoliosis are taller than the average population (Willner 1974, 1975). One may have suspected that despite this, deviation from normal was specifically confined to the spine itself. However, in the present study it is demonstrated that at least the legs and the spine have the same length proportion as in the healthy child.

## SUMMARY

The sitting height and its relationship to total height was compared for 164 girls with idiopathic adolescent structural scoliosis and 201 age-matched healthy controls It was demonstrated that although girls with scoliosis were taller than controls the relationship between trunk and legs was undisturbed

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These good results obtained during the first 10 years strongly suggested that dislocation later in life could be avoided by early diagnosis and treatment in the neonatal period Cases discovered late were often called "missed" cases In the beginning of the 1960s, however, some cases had not been discovered until the second year of life even in children born at maternity departments with a paediatric consultant, as well as those born at the small maternity departments

In 1962 we decided therefore to stress the need for examination of the hips of *all* newborns To assess the results it was decided to review *all infants born in 1963* who were treated because of late diagnosis

It was hoped that this would reveal why *such cases* had not been diagnosed in the neonatal period It was also hoped that it would shed some light on other diagnostic and therapeutic problems

## INVESTIGATION PROCEDURE

### *Diagnosis of preluxation and luxation in newborns*

Towards the end of 1962 all doctors at all maternity departments were requested by letter to examine within the *first few days of life* the hips of all infants born in 1963 They were also furnished with a *detailed* description of the examination technique Le Damany Ortolani s clicking test and testing of the stability of the hip joints by provoked subluxation (*Palmén 1961*)

Specially designed cards *for recording* diagnosed cases were issued *with* a request to return them filled in at the end of the *year* and at the same time to state how many children had been born alive at the department *that year*

### *Late diagnosis dislocations*

The chiefs of all orthopaedic departments were requested to make a separate list of all cases of luxation subluxation and dysplasia of the hip seen in infants born

Acta orthop scand 46, 90–101, 1975

Department of Paediatrics, Skövde and Department of Orthopaedic Surgery
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# LATE DIAGNOSIS DISLOCATION OF THE HIP JOINT IN CHILDREN

KURT PALMÉN & SOPHUS VON ROSEN

Accepted 15 x 74

In 1950 we began in Sweden to examine newborns for luxation and preluxation of the hip (Palmen 1953) The results obtained during the first few years were so good that in 1953 this examination was introduced as a routine method in all maternity departments where there was a paediatric consultant At that time about 30 per cent of all children born were delivered at such departments With the increasing centralisation of deliveries in the larger hospitals and the increasing availability of paediatric consultants, even in the smaller maternity departments, as many as about 85 per cent of all newborns are now examined at birth by paediatricians well trained in the manual examination of hip joints Today more than 99 per cent of all infants are delivered in maternity wards This has substantially improved the possibilities for diagnosing the condition

At the same time orthopaedic surgeons began to focus their attention on the condition which resulted in a close cooperation between paediatricians and orthopaedists (von Rosen 1956)

The possibility of diagnosing and treating congenital dislocation or preluxation of the hip at birth or within the first year of life has created many new problems Formerly the condition was first observed by the mother who noticed that the child limped when it began to walk and she consulted a paediatrician or a district physician, who referred the child to an orthopaedist However, these doctors have not, as a general rule, examined the hips at late health examinations of infants

As far as the orthopaedists are concerned, the situation meant a revision of the diagnostic criteria and treatment and, to some extent also, of the traditional concept of the pathogenesis of congenital dislocation of the hip

Thanks to the expansion of orthopaedics during the last few decades,

most district hospitals in Sweden now have an orthopaedic department All cases of diagnosed or suspected dislocation of the hip in the neonatal period are referred to the department of orthopaedics for investigation and treatment Only a few are treated by paediatricians, and then only if no orthopaedic consultant is available All cases of dislocation, subluxation or dysplasia of the hip diagnosed at a late stage are treated at orthopaedic departments (Here 'diagnosed at a late stage" is to be understood as diagnosed after the infant has left the maternity department )

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### *Late diagnosis dislocations*

The chiefs of all orthopaedic departments were requested to make a separate list of all cases of luxation subluxation and dysplasia of the hip seen in infants born

in 1963 and treated in 1963–1966 All cooperated and all consented to let us have copies of the hospital records and to lend us roentgen films After the end of each year we requested a report of all cases treated during the year, and in 1967 it was checked that all the cases seen during these years were reported Supplementary information was obtained from the records of maternity departments and from the parents

The children were reviewed in 1971–1972 In those cases where follow up had been concluded earlier, the chief clinician often reexamined the children again in order to get as long an observation period as possible

## RESULTS

### *Diagnosis of luxation—preluxation of the hip in newborns*

In 1963 children were born at 101 maternity departments and at 32 small maternity units in areas catered for by district physicians At 48 of the hospital departments there was a paediatric consultant who examined all the newborns

| | | No |
|---|---|---|
| A | Maternity departments with paediatric consultant | 48 |
| B | Small obstetric departments without paediatric consultant | [illegible] |
| C | Small maternity units with district physician | 32 |

*Distribution of luxation – preluxation*

| | Infants born | Number of cases | Frequency per thousand |
|---|---|---|---|
| A | 81,931 | 534 | 6 5 |
| B | 23,055 | 60 | 2 6 |
| C | 4 880 | 21 | 4 3 |
| | 109 866 | 615 | 5 6 |

The total number of live births in 1963 (deaths within first 7 days not included) was, according to Statistiska Centralbyrån, 111,662

The geographic distribution of the cases diagnosed coincided largely with that of the population, but with a few exceptions, e g

Obstetric department in Uppsala 44 cases among 2,803 newborns (15 7 per thousand)

Obstetric department in Västerås 61 cases among 2,113 newborns (29 per thousand)

At the seven departments of obstetrics in Stockholm the frequency of diagnosed cases varied widely, from 1 4 to 10 9 per thousand, with a mean frequency of 5 6 per thousand of 18,212 newborns

It might also be mentioned that the frequency of cases diagnosed was in

| | | |
|---|---|---|
| Falköping | 7 of 1,302 newborns, frequency | 5 4 per thousand |
| Malmö | 28 of 3,746 newborns, frequency | 7 5 per thousand |

In the evaluation of the frequencies it should be recalled that the figures stem from several different maternity clinics and that the examinations had been made by a large number of examiners, many of whom had had little or no earlier experience with examination of the hips of newborns A certain over diagnosis owing to inclusion of uncertain cases may also have occurred In the instructions for the examination method, however, it was pointed out that crepitations of the joint alone were not sufficient grounds to warrant a diagnosis of preluxation of the hip

*Late diagnosis luxation, subluxation and dysplasia*
*27 cases* were reported

Of these two were cases of different malformations and in three the diagnosis must be regarded as uncertain These cases were, however, included in the following classification

*Sex* 24 girls, 3 boys
*Obstetric presentation* cephalic 23 breech 4
*Premature birth* 2 (birthweight 1,280 and 2,300 g respectively)
*Born at maternity departments with paediatric consultant* 15 cases
*Born at small maternity units without paediatric consultant* 12 cases
*Family history of dislocation* In 6 cases out of 20 there was dislocation in the family (in 2 cases dislocation in older siblings)

*Symptoms that suggested dislocation*
*8 cases*, diagnosed at *less than 1 year* of age

one premature child admitted to the children's department where limited abduction was noticed when the child was 3 weeks old,
one girl referred at 3 months of age to the department of orthopaedic surgery by a physician who had been consulted by the mother regarding the child s malformed feet arthrogryposis with bilateral dislocation was found,
at the child health examination a 9 month-old girl had coarse crepitations of both hip joints, and was referred to the department

of orthopaedics, where mild unilateral limitation of abduction and mild dysplasia were diagnosed,
- in the other five cases the mothers had noticed differences in the lengths of the legs, in the medial thigh folds, in the degree of abduction in the hip joints, or in rotation of the legs when the child was standing. They therefore approached the physician at the child health centre and requested that the child be referred to a paediatric or orthopaedic clinic for further examination.

*Remaining 19 cases* discovered at more than 1 year of age
- in 17 cases it was the parents themselves who had noticed that the children limped and therefore sought advice,
- in only 2 cases did it appear to be the physician at the child health centre who had suspected dislocation at the routine examination.

*Roentgen examination at the time of the diagnosis showed*

| | Number of cases | | |
|---|---|---|---|
| | right hip | left hip | bilateral |
| Dysplasia | 3 | 1 | |
| Subluxation | | 3 | |
| Middle-high dislocation | 9 | 2 | 1 |
| High dislocation | 4 | 1 | 3 |
| | 16 | 7 | 4 |

One child with middle high dislocation had subluxation on the other side. (Here "middle-high" dislocation designates that the epiphyseal line between the neck and the head was roughly at the level of the Y-cartilage, "high" luxation, still higher.)

The four children with "dysplasia" had on one side a somewhat larger acetabular angle and a somewhat smaller ossification centre of the head. In three of these, abduction was limited (at 4, 5 and 6 months) and one was referred because of "coarse crepitations" on both sides. At attempted reduction under general anaesthesia no typical feeling of reposition was noticed in these four cases. In three of the cases the minor roentgen changes might be explained by an asymmetric position of the pelvis by exposure. In these cases, therefore, the diagnosis cannot be regarded as certain.

*Type of treatment*

| | |
|---|---|
| Reduction and immobilisation in plaster (with adductortenotomy, if necessary) | 16 cases |
| Reduction after traction and immobilisation in plaster | 4 cases |
| Open reduction | 5 cases |
| No primary treatment | 2 cases |

The two cases not treated were seen in

- a mentally retarded boy who at 3½ years of age had bilateral high dislocation,
- a girl, aged 2 years 2 months, with dysplasia and subluxation. At 9 years she was treated with osteotomy of the ilium.

Secondary operations were done in a further three cases: subtrochanteric osteotomy in one, acetabular plasty in one and osteotomy of the ilium in one.

*Findings at follow-up examination*

*Age at time of subsequent examination*

10–9 years: 12 cases, 8–7 years: 13 cases, 6–4 years: 2 cases

*Last roentgen examination* showed

| | |
|---|---|
| normal hip joints | 5 cases |
| practically normal hip joints | 9 cases |
| acetabular dysplasia + subluxation | 8 cases |
| severe "coxa plana" changes | 1 case |
| severely deformed joint | 2 cases |
| moderate pelvic deformity after osteotomy | 1 case |
| dislocation (untreated) | 1 case |

In *14 cases (52 per cent)* the results were thus good, i.e. the hips were normal or practically normal (Figure 1). The mild changes persisting in nine cases will probably disappear with time. Of these 14 cases the diagnosis had been made during the first half year of life in seven and during the second year of life in the others. All these cases could be treated with closed reduction and immobilisation in plaster (in two cases after previous traction treatment). In the three cases where the diagnosis had been uncertain the hips were normal.

*Eight cases* with persisting dysplasia with subluxation: in five of these the diagnosis had been made between the ages of 9 months and 2 years and in two at 2 years 2 months, and 2 years and [illegible] months,

*Figure 1. Middle high dislocation diagnosed at 2 years 4 months, treated by closed reduction and plaster for 7 months. The last X-ray at 10 years 3 months considered as practically normal.*

respectively. Three of these five were treated with open reduction and two also with osteotomy later.

In one case severe joint changes persisted with a flat irregular head, dysplasia of the acetabulum and mild subluxation. At 1 year 10 months bilateral high luxation was diagnosed and treated with closed reduction with adductortenotomy and immobilisation in plaster.

*Two cases* with severely deformed joints.

One of these cases was the previously-mentioned premature baby girl, in whom treatment with an abduction bandage was initiated at 3 weeks of age It appears that she had high dislocations on both sides from the very beginning, and these were not reduced by treatment with the bandage Open reduction at 5 and 7 months showed interposition of the capsule and the limbus

The other case was a girl who had bilateral pes equino-varus and in whom bilateral dislocation at the hip had been diagnosed at [illegible] years She was treated first with open reduction and later, at 4 and 5 years, with osteotomy.

The case with persisting untreated dislocation has been discussed in a previous section

## DISCUSSION

Of the children born in Sweden in 1963, late diagnosis dysplasia or dislocation was detected in 27 within the first 3–4 years of life Compared with the frequency before 1953 this meant a praiseworthy decrease by about 75 per cent This decrease was due mainly to the realisation and spread of knowledge of the significance of examination of the hips of newborns As many as 19 (70 per cent) of the 27 cases were not diagnosed before 1 year of age

Figures collected in recent years suggest a further reduction in the frequency of dislocation after 1 year of age Instead, however, the frequency of diagnosis of "dysplasia", with more or less severe subluxation, in infants has increased, especially between the ages of 3 and [illegible] months

The main purpose of the present investigation was to find out why the diagnosis was not made until a late stage and to assess the results of treatment

Careful examination by an experienced examiner is important for diagnosing congenital dislocation of the hip in the neonatal period The frequency of cases not diagnosed until a late stage was found to be more than twice as high among children born in small maternity units without a paediatric consultant, 12/28,000, compared with 15/82,000 at departments with such a consultant This difference was still more obvious in a large series of 127 cases diagnosed at a late stage and treated at orthopaedic departments in the years 1963–1966 (Palmen 1970) In that material the frequency was four times as high in children born at maternity units without a paediatric consultant

Fifteen of the 27 infants born in 1963 with congenital dislocation of the hip had been delivered at departments where newborns were routinely examined by paediatricians. In two of these cases the hips were probably not examined during the first few days of life:

- a premature baby girl with a birthweight of 1,280 g was transferred immediately to a paediatric department for intense treatment. At 3 weeks it was noticed that abduction was limited and bilateral dislocation was diagnosed.
- a boy with asphyxia at birth was transferred immediately to the paediatric department and no note was made about any examination of the hip. He was mentally retarded and dislocation was not diagnosed until he was 3½ years old.

In one case, examination of the hip at birth revealed a "click", but roentgen examination showed no signs of dislocation. The girl was therefore not treated or followed up and at 1 year 11 months dislocation was diagnosed. It is probable that the roentgen examination had not been technically adequate or that the films had been misinterpreted and therefore misleading.

The three cases of dysplasia, where the diagnosis may be questioned, were also seen in children examined by paediatricians.

Of the 12 infants born at small maternity units without a consultant paediatrician some deserve comment:

- the above-mentioned two cases with malformations, pes equinovarus and arthrogryposis, respectively,
- one girl who at 2 weeks of age was admitted to the department of paediatrics because of a skin disease. The parents themselves requested examination of the hips because a brother had previously been treated for preluxation as a newborn. Examination of the hips, however, revealed nothing remarkable and roentgen examination was not carried out. Dislocation was detected at 9 months of age.

Though some of the hips affected had probably not been examined during the neonatal period, our material contained several cases in which the children had been properly examined, in 9 of the cases by an experienced paediatric consultant. We must therefore expect that even in the future some cases will not be diagnosed until a late stage despite examination in the neonatal period. This is in line with experience in

other countries, such as Norway (Bull Hansen 1970), England (Mitchell 1972) and Jugoslavia (Brecelj 1973)

One of the reasons why a dislocation may not be diagnosed in the neonatal period is that the luxation is complete at birth, and not reduceable by manipulation, and any instability is not able to be felt (von Rosen 1968, Wilkinson 1972) At least one of the cases in the present material diagnosed at a late stage probably belongs to this group Amongst the cases diagnosed and treated immediately after birth there are some where a poor primary result of treatment can be explained by the possibility that luxation was total from the beginning and was not reduced by bandaging the legs in abduction

It is remarkable that in 22 of the 27 cases the parents themselves had suspected the dislocation, including 17 of the 19 cases discovered after 1 year of age In most cases the children had attended normal health check ups once or twice without the dislocation having been observed This underlines the importance of a careful examination of the hip at every medical examination during the first year of life In some cases the diagnosis was delayed because the mother s suspicion of dislocation had been ignored or because roentgen examination, which could have demonstrated the condition, had not been carried out

The favourable results of treatment with normal or practically normal results in 52 per cent of the cases can be explained by the relatively early treatment in eight cases before the age of 12 months and only in three cases after 2 years of age

Most cases were treated with closed reduction and immobilisation in plaster in some cases after treatment with traction and with or without adductortenotomy

In five cases where closed reduction proved unsuccessful, open reduction was performed Reduction was found to have been impossible owing to a narrow capsule and inverted limbus In four of these cases the dislocation was high, and in the fifth it was middle high The operations were not performed before 6–8 21, 23, 25, and 31 months of age respectively Two of the patients were not operated until after 3 and 6 months treatment with abduction in plaster after uncertain closed reduction This emphasizes the importance of early arthrography which can give detailed information of the state of the joint in un certain cases

Follow up examination of these five patients showed severely deformed joints in two and persistent dysplasia in the remaining three

The number of cases of dislocation of the hip diagnosed at a late

Fifteen of the 27 infants born in 1963 with congenital dislocation of the hip had been delivered at departments where newborns were routinely examined by paediatricians In two of these cases the hips were *probably not examined during the first few days of life*

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Follow up examination of these five patients showed severely deformed joints in two and persistent dysplasia in the remaining three

The number of cases of dislocation of the hip diagnosed at a late

stage has decreased in Sweden to such an extent that now only a few cases per year are referred to orthopaedic departments in regional hospitals. In several departments, including university departments, not even one case is seen per year. A question of practical importance is therefore whether it might not be advisable to centralise treatment of these cases to orthopaedic departments at universities and other regional hospitals, in order to obtain, among other things, sufficient cases for teaching purposes and continued research.


SUMMARY

Dating from 1953, the hips of newborn have been examined routinely all over Sweden. In 1963 more than 99 per cent of all newborns (about 110,000) were delivered at maternity departments, where such examination was recommended. 615 cases of preluxation or dislocation were diagnosed, which means a frequency of 5.6 per thousand. A high frequency reported in some hospitals suggests overdiagnosis.

To assess to what extent the examination of newborns has reduced the frequency of late diagnosis dislocation and dysplasia, extracts of the records were obtained concerning all infants born in 1963 and treated for dislocation of the hip in 1963–1966 at orthopaedic departments in Sweden.

Twenty-seven reported cases were analysed and the children were reviewed after 4–10 years. Fourteen (52 per cent) of the children were found to have normal or practically normal hips at the review. Eight still had dysplasia with subluxation and 3 had substantially deformed joints, one had moderate deformity and one, untreated, still had luxation.

Possible causes of late diagnosis are discussed and it is stressed

- that all physicians who examine newborns should be well versed in examination of the hip joints,
- that the hip joints should, when possible, be examined on two occasions during the first weeks of life, especially newborns predisposed to dislocation owing to heredity, breech presentation or different kinds of malformations,
- that it should be borne in mind that complete luxation, though rare, may exist already in the neonatal period,
- that one should not forget to examine the hips of newborns who, because of prematurity, asphyxia etc., are referred immediately for

intense treatment before routine examination of the hips has been carried out,

- that at child health centres one should not rely on the results of the examination during the neonatal period, but should always examine the hip joints

## ACKNOWLEDGEMENTS

*We thank the chiefs of the departments of orthopaedics and paediatrics for generous cooperation*

The investigation was supported by grants from the Medical Research Council

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*Key words* hip dislocation, congenital

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*Table 1 Occurrence of coxa plana in the right and left hips*

| | Left sided | Right-sided |
|---|---|---|
| Boys | [illegible] | 21 |
| Girls | 4 | 3 |

In all cases the measurements were performed using the orthoradiographic method described by Goldstein & Dreisinger (1950) During the observations hips knees and ankles were exposed separately Between the exposures the cassette with the X ray film was moved so that only one third of the film was exposed at a time During this procedure it was very important that the children lay motionless between the exposures and that the legs were parallel to the X ray table Consequently this method could only determine the presence of a difference in leg length and not the real length Tupman (1962) stated the standard error of this method as 0 2 per cent

To exclude the shortening of the affected leg which was caused by the deformation of the caput-collum part, the femur was measured from the distal part of the epiphysis of the trochanter major to the lateral condyle of the femur (a) The tibia was measured from the medial condyle to the medial malleole (b) (Figure 1)

The number of observations varied individually from 1–10 (Table 2) Twenty two children were followed up for two years after the completion of the treatment.


*Figure 1 Measuring sites*

Acta orthop scand 46, 102–107, 1975

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# DIFFERENCE IN LEG LENGTH IN CHILDREN WITH COXA PLANA DURING AND AFTER TREATMENT USING UNILATERAL UNLOADING

*A Study*

STIG WILLNER

Accepted 1 v 74

A shortening of the affected leg is often seen in children with unilateral coxa plana This shortening has frequently been said to be caused mostly by the deformation of the caput collum part of the femur and has been calculated to be about 1–2 cm However, on unloading the affected leg only, it was found that the measured difference in leg length was caused also by a shortening of the other parts of the femur and tibia (Edgren 1965, Morscher & Taillard 1965 and others)

Similar observations in unilateral coxa plana have been made in the present study The purpose of this study was to observe the development of the difference in leg length throughout the treatment and afterwards The observations have been made by means of orthoradiography

## MATERIAL

The material consisted of 55 children 48 boys and 7 girls who were treated for unilateral coxa plana by means of crutches and slings at the Orthopaedic Clinic Central Hospital in Linköping The observations were made from 1962 to 1968

The occurrence of coxa plana in the right and left hips can be seen in Table 1

The average age at the beginning of the illness was 6 1 ± 1 8* years for boys and 6 0 ± 1 6* years for girls

The duration of treatment was 24 2 ± 7 6* months

As growth rate is roughly constant among children between four and ten years of age, it is possible to look upon them as a homogenous group

* Average ± SD

*Table 4 Mean difference in leg length after the end of the treatment*

| | End of treatment | 6 | 12 | 24 | 36 | 48 | 60 |
|---|---|---|---|---|---|---|---|
| o of cases | 25 | 15 | 14 | 12 | 10 | 11 | 5 |
| lean (mm) | 19 9 | 16 7 | 12 9 | 9 4 | 8 6 | 4 6 | 2 2 |
| ± SD (mm) | 8 7 | 7 2 | 7.2 | 6 8 | 5 3 | 5 7 | 4 9 |
| ± SE (mm) | 1 7 | | 1 9 | 2 0 | 1 7 | 1 7 | 2.2 |

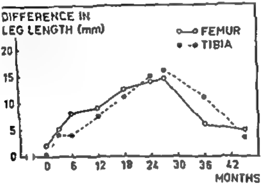


*Figure 2 Six-year old boy with a left sided coxa plana diagnosed in April, 1963 Treated for 30 months with slings and crutches*

out their disease (group 1) were compared to those who had loaded their affected leg over longer periods (group 2). Here a statistically significant difference could be found The difference in leg length was 21 0 ± 7 4 mm* in group 1 and 10 8 ± 3 5 mm* in group 2

As an example of this development 2 cases which were observed from the start of the treatment to a few years after its completion are shown in Figures 2 and 3

## DISCUSSION

The existence of a difference in leg length in unilateral coxa plana has been recognized for a long time (Caan 1924, Carpenter & Powell 1960, Edgren 1965, Morscher & Taillard 1965).

Carpenter & Powell found that a shortening of the affected leg could be seen in every case of coxa plana with a deformed caput femoris Edgren reported that the difference in the leg length was usually between 0 5 and 3 5 cm and asserted at the same time that this

* Average ± SD

*Table 2 Number of observations*

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Boys | 11 | 10 | 5 | | 5 | 6 | 4 | 3 | 2 | 2 |
| Girls | 2 | 1 | 2 | | 1 | | 1 | | | |

*Table 3 Mean difference in leg length in children with unilateral coxa plana treated with slings and crutches*

| | Duration of the treatment (months) | | | | | |
|---|---|---|---|---|---|---|
| | 0 | 6 | 12 | [illegible] | 24 | 36 |
| No of cases | 17 | 16 | 19 | 14 | 21 | 7 |
| Mean (mm) | 1 6 | 6 3 | 10 3 | 17 8 | 18 8 | 22 0 |
| ± SD (mm) | 2 1 | 3 2 | 4 4 | 7 0 | 8 2 | 5 5 |
| ± SE (mm) | 0 5 | 0 8 | 1 0 | 1 9 | 1 8 | 2 1 |

## RESULTS

When the treatment started no observable difference in the leg length could be found in most of the cases In five cases a shortening of the unaffected leg was noticed As could be expected the affected legs of all the cases were shorter during the treatment and the first visible signs of a difference in leg length could be noticed within six months This difference became more and more obvious as the treatment continued (Table 3)

After the treatment was terminated the children were allowed to use both legs Then the following development could be observed The *difference in the leg length distal of the trochanter part diminished* (Table 4) On the other hand, the shortening caused by the deformation of the caput femoris remained unchanged

The proportion of the observed difference in leg length located in the femur, distal to trochanter major, was 8 0 ± 5 5 mm* and that in the tibia was 7 9 ± 4 8 mm* at the completion of the treatment Thus the retardation of growth seemed to be equal in both bones

In order to be able to study the importance of immobilization in the above-mentioned difference in leg length distal to the epiphysis of the trochanter major, two groups of children were observed Those who followed the instructions as to the use of crutches and slings through-

* Average ± SD

*Table 4 Mean difference in leg length after the end of the treatment*

| | End of treatment | 6 | 12 | 24 | 36 | 48 | 60 |
|---|---|---|---|---|---|---|---|
| No of cases | 25 | 15 | 14 | 12 | 10 | 11 | 5 |
| Mean (mm) | 19 9 | 16 7 | 12 9 | 9 4 | 8.6 | 4 6 | 2 2 |
| ± SD (mm) | 8 7 | 7.2 | 7 2 | 6 8 | 5 3 | 5 7 | 4 9 |
| ± SE (mm) | 1 7 | | 1 9 | 2 0 | 1 7 | 1 7 | 2 2 |

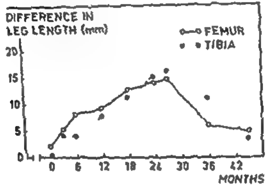


*Figure 2 Six year old boy with a left sided coxa plana diagnosed in April 1961 Treated for 30 months with slings and crutches*

out their disease (group 1) were compared to those who had loaded their affected leg over longer periods (group 2) Here a statistically significant difference could be found The difference in leg length was 21 9 ± 7 4 mm in group 1 and 10 8 ± 3 5 mm* in group 2

As an example of this development 2 cases which were observed from the start of the treatment to a few years after its completion are shown in Figures 2 and 3

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The existence of a difference in leg length in unilateral coxa plana has been recognized for a long time (Cam 1924 Carpenter & Powell 1960 Edgren 1965 Morscher & Taillard 1965)

Carpenter & Powell found that a shortening of the affected leg could be seen in every case of coxa plana with a deformed caput femoris Edgren reported that the difference in the leg length was usually between 0 5 and 3.5 cm and asserted at the same time that this

* Average ± SD

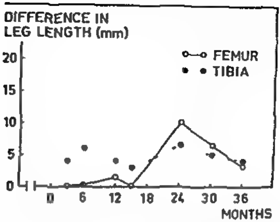


*Figure 3 Four year old boy with a right sided coxa plana diagnosed in May 1961 Treated with slings and crutches for 24 months During the first 15 months intermittent weightbearing of the affected leg*

shortening of the affected leg was caused not only by the deformation of the caput–collum part but also by the engagement of the rest of the leg

The retarded growth of the affected leg, distal to trochanter major is considered to be caused mainly by the immobilization of the leg and not by the illness itself (Ferguson 1963, Morscher & Taillard 1965, Edgren 1965) This observation is confirmed by this study

Gullickson et al (1950) for example pointed to the connection between skeletal growth and the activity of the muscles The absolute strength of the muscles was of less importance Ring (1961) was of the opinion that the muscles and skeleton of an extremity should be regarded as a functional unit Sundén (1967) considered the blood circulation of the bone tissue to be dependent on the activity of the muscles From this study it can be concluded that the difference in the leg length is caused by the lack of activity of the affected leg The difference could in certain cases be as much as 3 cm

An extremity that has been immobilized for a long time cannot begin to grow in a compensatory manner because of a premature closure of the epiphyses (Morscher & Taillard 1965) This study, however, shows that a few years' immobilization of a leg only delays the growth of the leg during the non-weightbearing period When the affected leg is again taking weight an actual compensatory growth starts which leads to a significant reduction of the difference in the leg length within a year after the completion of the treatment A residual difference, however, is noticeable for some years Any signs of an earlier closure of the epiphyses have not been observed

## SUMMARY

In unilateral coxa plana a shortening of the affected leg can often be found. This shortening affects not only the caput collum part of the femur but also the other parts of the femur and the tibia. In this study, however, the immobilization of the affected leg seemed to be the main reason for the observed difference in the leg length. Children who had not unloaded their affected leg as carefully as they should proved to have a smaller difference in leg length than those who had unloaded their affected leg according to the instructions. On the other hand compensatory growth of the affected leg was found when both legs were again taking weight. The difference in the leg length was significantly reduced one year after the completion of the treatment.


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*Key words* Coxa plana, leg shortening, compensatory growth


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Acta orthop scand 46, 108–118, 1975

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# USE OF ULTRASOUND TO DETECT FAT EMBOLI DURING TOTAL HIP REPLACEMENT

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Accepted 21 viii 74

*Venous fat embolism has been implicated as a possible cause of fatality* associated with total hip replacement or hemiarthroplasty of the hip in which methylmethracrylate cement is used Twenty-eight deaths have been reported (two following total knee replacement) in which autopsy findings in sixteen patients have demonstrated pulmonary fat emboli (Adams et al 1972, Harris 1970, Hyland & Robins 1970, Cohen & Smith 1971, Charnley et al 1971, Daniel et al 1972, Burgess 1970, Dandy 1971, Durbin et al 1970, Gresham & Kuczynski 1970, Greshan et al 1971, Phillips et al 1971, Powell et al 1970, Thomas et al 1971) In three patients bone marrow emboli were seen and one patient had fat emboli in the myocardium (Kepes et al 1972, Sevitt 1972)

A recent report by Kelly et al (1972) demonstrated that ultrasound provided a simple and reliable method for detecting fat emboli in dogs and humans after long-bone fractures We have utilized the Doppler effect with a simple noninvasive ultrasonic technique to detect fat emboli in the venous return from the lower extremity in an unselected group of patients undergoing total hip replacement

## MATERIAL AND METHODS

Thirty four unselected patients undergoing total hip replacement were studied by monitoring over the common femoral vein of the operated extremity with a Doppler ultrasonic flowmeter The Medsonics Doppler flowmeter model BF4A with a signal of 5 8 MHz was used in the first nineteen cases, the Parks Doppler flowmeter model 802 with a standard pencil probe with an output signal of 9 7 MHz was used in thirteen cases, and the Parks Doppler flowmeter model 801 with a fifteen degree flat probe was used in two cases

Supported by the Joint Implant Surgery and Research Foundation

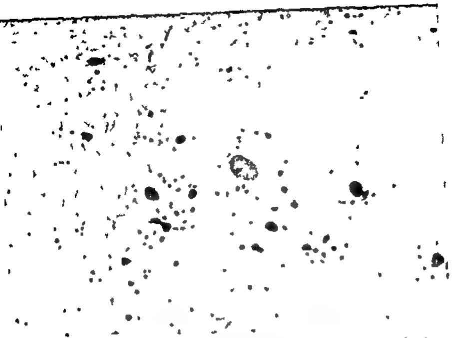

*Figure 1 Cryostat frozen section preparation demonstrating number and relative size of fat emboli in femoral vein aspirate drawn during peak ultrasound activity Stained with oil red O (× 310)*

Blood flow in the common femoral vein was monitored continuously throughout the operative procedure Sounds were recorded on a Sony cassette tape recorder in thirteen cases four of these recordings were dubbed onto a one inch magnetic tape, annotated by a reference time code to facilitate pulses of interest and pertinent portions of the data were digitalized at 5000 samples per second From this data impulses to be analyzed were selected and reduced on a computer to yield an energy spectrum analysis and Fourier analysis Frequency regions from 3 to 3000 Hz and in selected cases up to 7500 Hz were studied In three cases the surgeon (COB) injected less than 1 $cm^3$ of clear liquid marrow fat and in two cases injected 2 $cm^3$ of room air into a small vein exposed in the operative field Sounds over the common femoral vein were recorded analyzed and compared to the sounds recorded during the total hip procedure

Twenty one patients also underwent femoral vein catheterization prior to surgery Under sterile conditions and fluoroscopic control a number seven french disposable Cordis angiographic catheter was passed percutaneously into the brachial vein and manipulated into the common femoral vein Blood samples were drawn preoperatively during the period of peak activity heard with the ultrasound flowmeter and at the end of the operation. A control was drawn simultaneously from an arm vein All samples were drawn in glass syringes which had been washed in acetone and dried carefully All laboratory glassware was washed twice in alcohol-ether and dried carefully

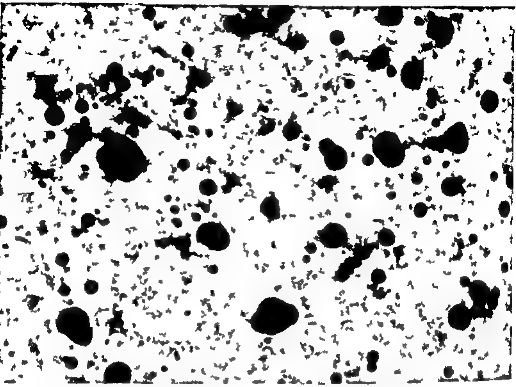

*Figure 2 Photomicrograph of millipore filter containing fat emboli in femoral vein aspirate drawn during peak ultrasound activity Filter stained with Sudan II (× 310)*

The aspirated blood was divided into two samples A 3 $cm^3$ aliquot was allowed to clot and analyzed for fat emboli by the cryostat frozen section test described by *Hausman et al (1971) The remaining blood (7 $cm^3$ per specimen) was anticoagulated* with EDTA and analyzed for fat emboli by millipore filtration and triglyceride determination as described by Gurd (1970)

## RESULTS

As the femoral component was inserted burbling sounds were heard in some cases but characteristic "chirps" were heard in thirty two of the thirty four cases studied Their intensity and frequency increased rapidly as the prosthesis was firmly seated After variable amounts of time the chirps became more distinct decreased in frequency and intensity, and gradually diminished

No sounds were detected in the two cases in which a Parks Doppler model number 801 with a fifteen degree flat probe taped over the groin was used In each case the probe came loose with movement of the extremity during the procedure It is essential that the ultrasound

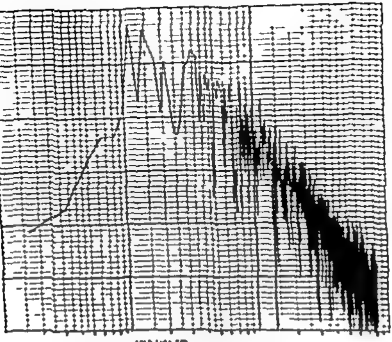

*Figure 3 Energy density spectrum analysis of the chirps recorded with the ultrasound flowmeter during insertion of the femoral component Note peak in region of 100 cycles per second with a steady uniform decrease in the higher frequency regions*

probe be coupled to the skin with an aqueous gel to allow for transmission of the echo

Both the cryostat frozen section of clot and analysis for fat emboli by Gurd (1970) established that during insertion of the femoral component when the sounds recorded by the Doppler flowmeter were at their peak, fat emboli were released into the venous circulation (Figures 1 and 2) At this time during the operation the mean number of fat globules per high power field in the frozen section of clotted blood drawn from the femoral vein was 79 (control 1 7, $P<0\,001$) The mean number of fat globules on the millipore filter was 360 per high power field (control 6 8 $P<0\,001$) The mean drop in triglyceride level after filtration was 27 8 mg per 100 ml (control 1.2, $P<0\,001$) In each case however the preoperative and postoperative values were almost identical to the controls

An energy density spectrum analysis and Fourier analysis carried

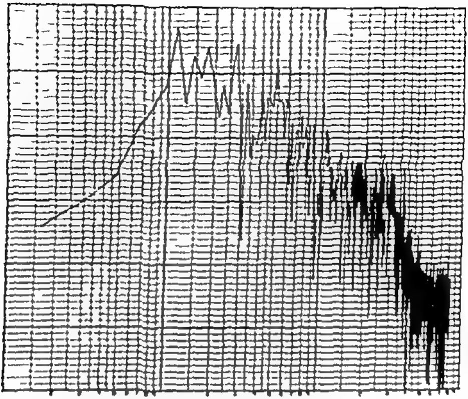


*Figure 4 Energy density spectrum analysis of the pure chirps recorded with the ultrasound flowmeter during known injection of liquid marrow fat The curve is indistinguishable from the energy density spectrum analyses carried out on the patients during insertion of the femoral component*

out on four patients revealed similar frequency contents The audible chirps were shown to be composed of many smaller distinct sounds that could not be distinguished by the human ear (Figure 3). The frequency analysis of the chirps showed a broad band of energy content ranging from 10 to 3000 Hz peaking between 50 and 100 Hz The distinct chirps lasted up to 0 4 s while the smaller units ranged from [illegible] to 5 ms in duration The interval between the sounds was 10 to 15 ms The frequency spectrum of the chirps varied in each patient and from patient to patient No definite signature was obtained

The control injection of liquid marrow fat was heard as pure chirps by the observer (Figure 4) and the control injection of air was heard as burbling (Figure 5) Thus to the observed it was apparent that two different sounds were heard, but energy density spectrum analyses were unable to give a signature to either type of sounds or equate them to the sounds heard during insertion of the femoral component in total hip replacement

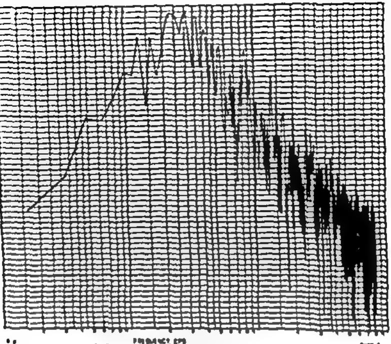


*Figure 5 Energy density spectrum analysis of the burbling sounds recorded with the ultrasound flowmeter during known injection of air The curve is indistinguishable from the energy density spectrum analyses carried out on the patients during insertion of the femoral component*

The average duration of activity was 4 2 min Sounds lasted from just a few chirps to 11 min in duration The length of activity varied with surgical technique, i e whether a vent was used during insertion of the cement and prosthesis into the femur (Figure 6). The longest period of activity was recorded in Group I in which no vent was used The mean duration of activity was reduced by almost one-half when a catheter attached to suction was used as a vent (Group II, $P < 0\ 01$) In Group III (drill hole as a vent) the mean duration of activity was only 2 5 min ($P < 0\ 01$ compared to Group I) Group IV included two patients who underwent revision of a previously cemented prosthesis and minimal ultrasound activity and fat emboli were detected

During the remaining surgical procedure with continuous monitoring with the ultrasound probe in thirty two patients a few chirps were heard during reaming the acetabulum (one case), during seating the acetabular component (five cases) and during insertion of the cement

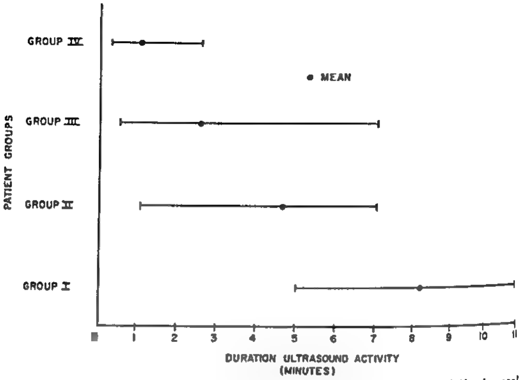


*Figure 6 Duration of ultrasound activity recorded during insertion of the femoral component Longest periods of activity were heard when no vent was used Shortest duration of activity was recorded in patients with a previously cemented prosthesis*

into the femur (ten cases) In each instance only a few transient chirps were heard

## DISCUSSION

Ultrasound has been widely used to monitor blood flow in arterial and venous peripheral vascular disease (Strandness et al 1966, Sigel et al 1972), blood pressure (Kemmerer 1967), arterial flow during arterial and ventricular arrhythmias (Benchimol et al 1969), fetal heart beat (Bernstine & Callagan 1966), to detect venous air emboli (Edmonds Seal & Maroon 1969) and recently to detect venous fat emboli following fractures of the lower extremity (Kelly et al 1972)

The ultrasonic instruments can also detect fat emboli during total hip replacement In the cases studied fat emboli were released every time during insertion of the femoral component and rarely in very small quantities during reaming the acetabulum, seating the acetabular component or during insertion of the cement into the femur

Characteristic "chirps" were heard with the ultrasound which were

proven to be fat emboli by blood analyses Kelly et al (1972) recently described these same "chirps" as representing fat emboli released by fractures involving the femur or tibia They carried out sonogram frequency analyses which showed that the loudest chirps had a frequency of 2 5 to 8 0 kHz, a duration of 2 to 3 ms and an occurrence of up to three emboli in 20 ms We carried out an energy density spectrum analysis and Fourier analysis which showed similar duration and interval for the sounds as Kelly's study but the frequency of our sounds varied from 50 to 100 cycles per second—much lower than Kelly described Our analyses also demonstrated that the audible sounds were composed of many smaller distinct sounds not detected by the listener The frequencies of these sounds varied in each patient and from patient to patient although they sounded similar to the listener We were not able to establish a definite signature for each sound This may be due to the large number of variables different sizes of fat globules, adherence of platelets, other products of reaming such as fragmented red and white blood cells, possible air emboli, summation effect of different fat emboli being detected as a single large embolus by the Doppler probe, changes in flow rate, turbulence, and fat emboli being recorded more than once as they passed through the ultrasound beam

The fat studies proved the nature of the particles causing the chirps, but the ultrasound flowmeter did not Patterson & Kessler (1969) have shown that ultrasound gives little information about the nature of microemboli both bubbles and solid particles produced similar echos Circulating bubbles have been described as "chirps", "plobs" and sounds similar to high pitched scratching noise produced when a phonograph needle strides across a moving record (Maroon et al 1968)

Clinically we were able to differentiate two sounds during sealing of the femoral component a few burbling sounds initially as the prosthesis was being inserted in a few cases and the "chirps" which were present in each case monitored The burbling sounds were similar to the listener as the sounds heard when a known sample of air was injected into a small exposed vein The chirps were similar to the sounds heard when a known sample of liquid marrow fat was injected into a small exposed vein and by blood analyses were proven to be fat emboli Thus although the observer felt he clinically could differentiate the sounds, the energy density spectrum analysis could not (both were very similar) These analyses may be too precise, but further support Patterson & Kessler's (1969) contention

Ultrasound does however give useful information about the quantity of particles Patterson & Kessler (1969) demonstrated a direct linear relationship between the number of particles and the number of echoes per unit time Our data suggest that air embolism does occur in some cases of total hip replacement during insertion of the femoral component, but in every case a larger and more significant amount of fat emboli are released into the venous circulation Ultrasound is an excellent clinical tool to monitor the amount of fat emboli during the operative procedure Significant decreases in the quantity of fat emboli can be maintained by proper positioning of the femur, thorough evacuation of marrow contents after reaming and by the proper use of a vent (suction tube or drill holes) during the procedure

## SUMMARY

Use of the Doppler principle with an ultrasound flowmeter provided a method of detecting fat emboli during total hip replacement A measure of the quantity of fat emboli and when the embolism occurs during the operative procedure is possible with this method

By the use of a suction catheter inserted in the intramedullary canal or the placement of large drill holes in the lateral cortex of the femur the amount of fat released into the venous circulation can be reduced

Although no definite signature could be obtained for the audible "chirps" by energy density spectrum analysis the observer could readily distinguish these chirps from the burbling noise produced by air emboli Ultrasound is an easy, noninvasive and reliable technique for detecting fat emboli during total hip replacement

## ACKNOWLEDGEMENTS

The authors would like to thank John C Cerrone, M D Robert W Woods M D Charlotte Yamada Patsy K Richards Mark Trummel Ph D and the staff of the Jet Propulsion Laboratory and James Pugh Ph D for their assistance in this study

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*Key words* ultrasonics embolism fat hip joint, hip

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Acta orthop scand 46, 119–122, 1975

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# TRAUMATIC ANEURYSM OF THE COMMON FEMORAL ARTERY AFTER HIP ENDOPROSTHESIS

## *A Case Report*

A Kroese & A Mollerud

Accepted 21 v 74

Arthroplasty of the hip with insertion of a hip endoprosthesis is a frequent procedure at the Orthopaedic Department of Aker Hospital, Oslo (Arnold et al 1974) The indication for the operation is usually osteoarthritis of the hip or fractured femoral neck in patients more than 70 years old

The following case represents a rare arterial trauma after a femoral head replacement with a Christiansen prosthesis (Christiansen 1974)

### CASE REPORT

A 78-year old woman was treated with osteosynthesis for a fractured femoral neck She was readmitted 1 year later because of pains in the hip joint the suspicion of femoral head necrosis was verified radiographically The patient was reoperated and a Christiansen endoprosthesis was inserted The posterior curved exposure of the hip joint ("Southern exposure") (Nicola 1966) is most usual in this type of operation

However in this case a more ventral approach was used (Muller 1965) Per operatively it would be decided whether a total or a partial hip replacement was to be performed The incision ran from the superior iliac spine along the greater trochanter and the femoral shaft The joint capsule was exposed between the facia latae muscle and the medial gluteal muscle The capsule was opened and a Christiansen femoral head prosthesis was used for replacement of the necrotic head.

The first postoperative days were uncomplicated On the 6th postoperative day however the patient deteriorated rapidly with a low blood pressure and a low hemoglobin In the left iliac fossa a tumor was palpated which in a few days extended almost to the left costal arch The clinical diagnosis was retroperitoneal hemorrhage although arteriograms were normal She was unable to move her operated hip because of great pain

The retroperitoneal hematoma was evacuated through an oblique incision in the left iliac fossa but she improved only slightly

Gradually the femoral pulse on the operated side became more accentuated a

transcutaneous Doppler flowmeter in evaluation of occlusive arterial disease. *Surg Gynec Obstet* 122, 1039–1045
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*Key words:* ultrasonics, embolism, fat; hip joint, hip

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A Kroese & A Møllerud

Accepted 21.x 74

Arthroplasty of the hip with insertion of a hip endoprosthesis is a frequent procedure at the Orthopaedic Department of Aker Hospital, Oslo (Aamold et al 1974) The indication for the operation is usually osteoarthritis of the hip or fractured femoral neck in patients more than 70 years old

The following case represents a rare arterial trauma after a femoral head replacement with a Christiansen prosthesis (Christiansen 1974)

## CASE REPORT

A 76 year old woman was treated with osteosynthesis for a fractured femoral neck She was readmitted 1 year later because of pains in the hip joint the suspicion of femoral head necrosis was verified radiographically The patient was reoperated and a Christiansen endoprosthesis was inserted The posterior curved exposure of the hip joint ("Southern exposure") (Nicola 1966) is most usual in this type of operation

However in this case a more ventral approach was used (Müller 1965) Per operatively it would be decided whether a total or a partial hip replacement was to be performed The incision ran from the superior iliac spine along the greater trochanter and the femoral shaft The joint capsule was exposed between the facia latae muscle and the medial gluteal muscle The capsule was opened and a Christiansen femoral head prosthesis was used for replacement of the necrotic head

The first postoperative days were uncomplicated On the 6th postoperative day however the patient deteriorated rapidly with a low blood pressure and a low hemoglobin In the left iliac fossa a tumor was palpated which in a few days extended almost to the left costal arch The clinical diagnosis was retroperitoneal hemorrhage although arteriograms were normal She was unable to move her operated hip because of great pain

The retroperitoneal hematoma was evacuated through an oblique incision in the left iliac fossa but she improved only slightly

Gradually the femoral pulse on the operated side became more accentuated a

*Figure 1* Arteriogram shows contrast leakage from a traumatic femoral aneurysm into a hematoma

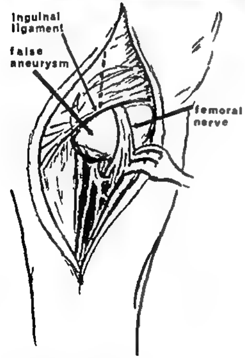


*Figure 2* The femoral nerve compressed between the aneurysm and the inguinal ligament

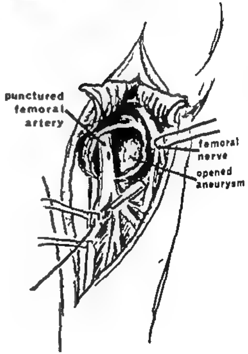


*Figure 3* The punctured femoral artery exposed after removal of the hematoma

"thrill" was palpated and a systolic "bruit" was auscultated The clinical diagnosis of "false aneurysm" of the common femoral artery was verified by a new angiography (*Figure 1*) *Through an incision parallel to the femoral artery a false* aneurysm 8 cm in diameter, was exposed The femoral nerve was compressed between the bulging aneurysm and the inguinal ligament (Figure 2) After the hematoma within the aneurysm was removed bleeding started from a small opening in the artery 2 cm proximal to the profunda bifurcation It was controlled by direct suture (Figure 3) The tension of the nerve had probably caused the patient's severe pains A few days after the last operation the patient was mobilized and she recovered without further complications

## DISCUSSION

Several reports of complications in arthroplastic surgery of the hip have been published In addition to postoperative hemorrhage, infection and thrombosis (Darke 1972), some technical problems have been described rupture of the iliac vein from reaming the acetabulum (Harris 1970), loosening of the endoprosthesis (Wilson & Scales 1970), and hypotension and possibly cardiac arrest and pulmonary embolism with the use of acrylic bone cement (Daniel et al 1972, Harris 1970) However, arterial trauma in hip surgery is a rare complication (Horton 1972) False aneurysm of the deep femoral artery after osteotomy (Meyer & Slager 1967) or osteosynthesis of the *femoral neck* (Mallory 1972) *has been reported* Because iliac and common femoral vessels are so near the acetabulum and the pubic bone it is surprising that damage to them is relatively rare in surgery of the hip Using the antero-lateral approach to the hip joint, a Homan retractor is often placed with its tip behind the superior edge of the pubic bone, exerting a levering action to keep the operating field clear from soft tissue (Figure 4) The tip of the retractor had *probably*

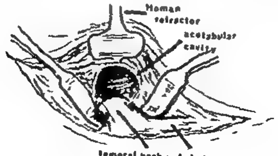


*Figure 4 The Homan retractor with its tip behind the superior edge of the pubic bone*

*Figure 1 Arteriogram shows contrast leakage from a traumatic femoral aneurysm into a hematoma*

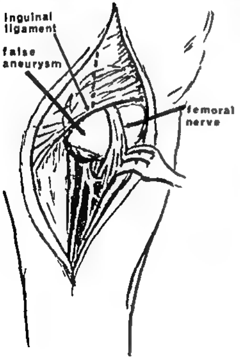


*Figure 2 The femoral nerve compressed between the aneurysm and the inguinal ligament*

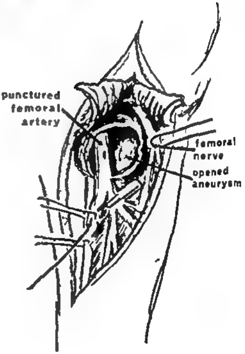


*Figure 3 The punctured femoral artery exposed after removal of the hematoma*

Acta orthop scand 46, 123–134, 1975

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# PERFORMANCE OF BK AMPUTEES USING PTB PROSTHESES

SIDDHARTHA GANGULI, KALI S BOSE & SUDHANSA R DATTA

Accepted 21 viii 74

It is generally claimed that the patellar tendon-bearing (PTB) prosthesis, which is now in widespread use, enables the below-knee amputee to achieve a near-normal performance level by virtue of its certain distinct biomechanical advantages when compared to other conventional types of below-knee prostheses In view of the paucity of any objective studies supporting such a claim, a systematic investigation was undertaken to assess ergonomically the performance level or, in other words, the degree of functional restoration in a group of below-knee amputees using PTB prostheses

## MATERIAL

The investigation material consisted of 10 adult male below-knee amputees all wearing PTB prostheses fabricated at the Artificial Limb Centre, Department of Orthopaedics University College of Medicine (Goenka Hospital), University of Calcutta The brief case histories of these subjects are presented in Table 1

The amputation in each of the 10 test cases was traumatic At the time of reporting to the O P D of the Department of Orthopaedics, five of the subjects complained of loss of limb and desired to be fitted with suitable prostheses, whereas the other five demanded replacement of the conventional BK prostheses which they had been using for quite some time

The site of amputation was left in seven out of the 10 cases studied The stump length measured from the knee joint line to the distal end of the stump ranged between 9 and 22 cm (arithmetic mean 15 cm) All stumps were conical in shape and the power of the flexors and extensors was observed to be good in each case

The design of the PTB prosthesis was kept identical in each case and it generally conformed to the standards laid down by Radcliffe & Foort (1961), the only variation being in the modified SACH footpiece (that is with solid ankle,

punctured the common femoral artery in this case, and a false aneurysm had developed The antero lateral approach is probably less suited for the implantation of a Christiansen prosthesis where the hip has to be inwardly rotated strongly in order to get it placed into the acetabulum

SUMMARY

A case with a rare arterial trauma after a femoral head replacement with a Christiansen prosthesis is presented The common femoral artery was penetrated by the tip of a Homan speculum and a false aneurysm developed

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*Key words* arthroplasty hip Christiansen s hip prosthesis Homan s retractor arterial trauma

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*of the test group subjects*

| Preparation for prosthetic fitting | Date of final fitting & delivery of prosthesis | Body weight with prosthesis (kg) | Weight of prosthesis (with shoe) (kg) | Date of testing |
|---|---|---|---|---|
| Stump exercise gradual stretching of 20° flexion contracture in knee, quadriceps resistance exercises for 1 month | 24 5 69 | 37 8 | 1 6 | 27 2 71 |
| Quadriceps drill for 1 month | 20 6 69 | 49 0 | 1 9 | 1 3 71 |
| Quadriceps drill for 1 month | 15 7 70 | 56 0 | 1 9 | 2 3 71 |
| Quadriceps drill for 1 month | 15 7 70 | 45 5 | 2.3 | 23 3 71 |
| Quadriceps drill for 1 month | 7 5 69 | 39 6 | 1 7 | 26 4 71 |
| Quadriceps drill for 1 month | 3 6 69 | 43 0 | 2.5 | 28 4 71 |
| Quadriceps and stump exercises for 2 months | 2 7 70 | 46 5 | 2 5 | 27 5 71 |
| Quadriceps drill for 1 month | 17 7 70 | 44 7 | 2 7 | 2 6 71 |
| Quadriceps drill for 2 months | 24 10 70 | 70 0 | 2 1 | 9 6 71 |
| Quadriceps drill for 1 month | 21 6 72 | 50 5 | 2 0 | 3.3 72 |

investigation had been finally checked by a clinical team consisting of an orthopaedic surgeon a bioengineer and a *prosthetist* employing a subjective procedure (Ganguli et al 1973) and discharged to resume his normal activities

Although the principal aim of this investigation was to derive standards of optimum performance for below knee amputees wearing PTB prostheses, departure

*Table 1 Brief case histori*

| Case no | Name | Age (years) | Height (cm) | Body weight without prosthesis (kg) | Year of amputation & means of ambulation on first visit to UCMGH* O P D | Side of amputation | Stump length (cm) |
|---|---|---|---|---|---|---|---|
| 1 | BKD | 17 | 161 | 36 0 | 1968 Axillary crutches | Left | 13 |
| 2 | AKM | 47 | 161 | 47 1 | 1930 Conventional BK prosthesis | Right | 11 |
| 3 | AKS | 35 | 160 | 54 1 | 1962 Conventional BK prosthesis | Left | 14 |
| 4 | PG I | 27 | 164 | 43 2 | 1961 Conventional BK prosthesis | Right | 20 |
| 5 | DPP | 20 | 148 | 37 9 | 1968 Not ambulatory | Left | 9 |
| 6 | SSM | 40 | 167 6 | 40 5 | 1961 Conventional BK prosthesis | Left | 17 |
| 7 | PG II | 24 | 163 | 44 0 | 1967 Axillary crutches | Left | 16 |
| 8 | BRA | 45 | 163 | 42 0 | 1966 Conventional BK prosthesis | Left | 23 |
| 9 | SD | 20 | 178 2 | 67 9 | 1970 Axillary crutches | Left | 13 |
| 10 | AM | 24 | 158 | 48 5 | 1971 Axillary crutches | Left | 15 |

* UCMGH University College of Medicine (Goenka Hospital) University of Calcutta, Calcutta, India

spongy heel and a spongy toe break at the middle third of the foot) The weight of the prosthesis ranged between 1 7 and 2 7 kg (arithmetic mean 2 1 kg), that is proportionately it varied between 3 and 6 per cent (arithmetic mean 4 5 per cent) of the total body weight of the rehabilitee including shoes and prosthesis

Each rehabilitee member of the test group before being selected for the present

*Figure 1 A test group subject performing the walking test*

## RESULTS

The means and standard deviations of all the parameters observed, namely, energy expenditure (Kcal/min/kg), oxygen consumption (L/min, STPD/kg), pulmonary ventilation (L/min, BTPS/kg) and peak heart rate (beats/min) for both the groups are presented in Table 3 The percentage increases in the test group over the control group subjects for all the said parameters, are shown in Figure 2 The means and standard deviations as well as the percentage increases for the first three of the above mentioned four physiological parameters were calculated from the respective net values, that is, per unit body weight (kg) in order to eliminate the influences of difference in body build among the subjects

*Table 2 Personal data of control and test group subjects means and standard deviations*

| | Age (years) | Height (cm) | Body weight (kg) | Body surface area ($m^2$) |
|---|---|---|---|---|
| Control group ($n = 16$) | | | | |
| Mean | 28 4 | 164 3 | 51 0 | 1 54 |
| SD (±) | 7 05 | 7 12 | 6 56 | 0 10 |
| Test group ($n = 10$) | | | | |
| Mean | 29 9 | 163 1 | 48 3 | 1 47 |
| SD (±) | 11 00 | 7 95 | 9 33 | 0 156 |

Note In the above Table body weights of the test group subjects are the total body weights including the weights of the prostheses and shoes

from normal in the test group was studied as a matter of interest For this purpose a control group consisting of 16 normal healthy sedentary adult males was formed The means and standard deviations of the control group subjects' personal data are presented in Table 2 along with those of the test group subjects

## METHODS

For the assessment of the degree of functional normality restored in the test group subjects an objective testing procedure using the ergonomic approach (Datta et al 1972 Ganguli et al 1971 Ganguli et al 1973) was adopted The battery of tests consisted of two *static performance tests* (i) sitting upright in a chair and (ii) standing erect from the sitting position and maintaining the standing posture for 2 minutes, two *dynamic performance tests* (i) walking a distance of 1 km on level ground at a speed of 3 km/h for a period of 20 minutes at a stretch and (ii) ascending 127 steps of a staircase each step of which was 14 2 cm high and the total height climbed being 18 m at a rate of 7 48 m/min and 7 37 m/min for the control group and the test group subjects respectively and a *step test* for measuring exercise tolerance during which the subject was made to step on and off a 20 cm high stool at the rate of 15 steps/min for a period of 10 minutes The *static and dynamic* tests were chosen so as to represent the basic body postures and acts that are necessary for leading a normal life The control group subjects also were administered with the same set of tests As a typical example of the tests the walking test is illustrated in Figure 1

While the *dynamic* tests were being performed the speeds were kept uniform by having an investigator to closely accompany the subject with a stopwatch in hand for timing the rate of motion over measured distances For the *step test* the rate was maintained approximately constant with the help of a metronome

During each test the physiological factors studied were energy cost and the corresponding cardio respiratory responses (namely oxygen consumption pulmonary ventilation and peak heart rate) of the subject

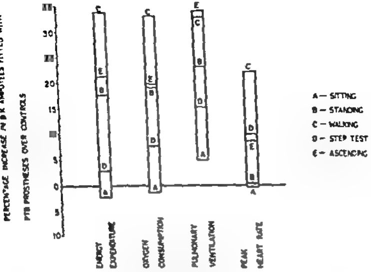


*Figure 2* *Percentage increases in the values recorded for the test group over those for the control group subjects*

## DISCUSSION

Possible sources of discomfort in the below-knee amputee fitted with a PTB prosthesis and adopting a sitting posture are 'inadequate hamstring channels, an unduly high posterior brim, impingement of the higher medial and lateral walls onto the back of the prosthesis, or unduly anterior or distal placement of the tabs of the cuff' None of the test group subjects of the present investigation, however, complained of any discomfort during the sitting test and this was also confirmed from the energy expenditure values and the cardiorespiratory responses recorded As a matter of fact, since this test does not involve total weightbearing by the lower extremities, contrary to the standing activity no increase over the control group values was expected in the test group results The results, on the other hand, showed slightly lower values in the case of the rehabilitees which might be due to the loss of a tangible portion of the metabolically active tissues of one lower limb

In the standing position, the test group subjects were observed to spend 17.2 per cent more energy than the control group subjects This increase can be attributed to the special demand placed on the amputated leg by the built in design provisions of the PTB prosthesis, for fulfilment of the weightbearing function The surfaces of the PTB

*Table 3 Physiological parameters observed means and standard deviations*

| Description of parameters | Control group | | | | | Test group | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Sitting | Standing | Walking | Ascending | Step test | Sitting | Standing | Walking | Ascending | Step test |
| Energy expenditure (Kcal/min/kg body wt*) | | | | | | | | | | |
| Mean | 0 0208 | 0 0256 | 0 0444 | 0 0776 | 0 0790 | 0 0203 | 0 0300 | 0 0591 | 0 0934 | 0 0815 |
| S D (±) | 0 00401 | 0 00649 | 0 00874 | 0 01107 | 0 01206 | 0 00464 | 0 00366 | 0 01069 | 0 01300 | 0 01804 |
| Oxygen consumption (L/min STPD/kg body wt*) | | | | | | | | | | |
| Mean | 0 0044 | 0 0055 | 0 0094 | 0 0166 | 0 0159 | 0 0043 | 0 0065 | 0 0124 | 0 0197 | 0 0170 |
| S D (±) | 0 00089 | 0 00138 | 0 00186 | 0 00242 | 0 00251 | 0 00103 | 0 00140 | 0 00221 | 0 00292 | 0 00368 |
| Pulmonary ventilation (L/min BTPS/kg body wt*) | | | | | | | | | | |
| Mean | 0 134 | 0 155 | 0 249 | 0 369 | 0 389 | 0 140 | 0 190 | 0 327 | 0 491 | 0 447 |
| S D (±) | 0 0277 | 0 0411 | 0 0621 | 0 0475 | 0 0607 | 0 0342 | 0 0367 | 0 0762 | 0 0901 | 0 1159 |
| Peak heart rate (Beats/min) | | | | | | | | | | |
| Mean | 83 2 | 89 6 | 94 2 | 125 0 | 115 2 | 82 8 | 89 8 | 114 0 | 136 4 | 124 4 |
| S D (±) | 8 60 | 9 79 | 11 94 | 3 93 | 4 76 | 7 73 | 12 59 | 16 64 | 12 88 | 12 86 |

* For the test group subjects body weight has been considered without the weight of the prosthesis and shoes

During the stair ascending test, the below-knee prosthetic rehabilitees were not found to be inconvenienced by adopting the normal alternating (that is, step-over-step) method of climbing a staircase and none of them had any difficulty such as catching the toe against the riser of the stairs Their control of knee stability was also found to be satisfactory The percentage increase in their energy expenditure over that of the control group subjects was observed to be 20 5 In a study carried out by Hirschberg & Ralston (1964), the energy expenditure per step for stair climbing was seen to be 40 to 50 per cent higher in handicapped hemiplegic subjects when compared with normal, healthy subjects The 20 5 per cent increase over the normal value in below-knee amputees fitted with PTB prostheses, therefore, seems to be reasonable as this extra energy demand may be attributed to carrying the extra load of the prosthesis, which expends extra energy A question which may pertinently be raised here is why the increase in energy expenditure of the test group subjects over the control group subjects was proportionately lower for the activity of stair ascending than it was for walking on level ground This may be explained in the following way While the level walking speed for both groups of subjects was kept at the same (that is, 3 0 km/h), the rate of stair ascent of the normal group was 7 48 m/min as against 7 37 m/min in the amputees, to suit their comfort and convenience Furthermore, although stair climbing involves more active positive (that is, anti gravity) work on the part of the muscles, the accelerations and decelerations are less vigorous as compared to walking on the level

The step test proved to be of least use and it could not furnish any interesting information since the test group subjects could not always maintain the rate of stepping as regularly and precisely as the control group subjects They were also found to be at a disadvantage in stepping off the stool backwards, due to the absence of kinesthetic and tactile senses in the prosthetic leg

## CONCLUSION

Owing to the dearth of published data on the optimum performance standards of the below knee amputee PTB prosthesis system, the test group results had to be compared with the normal performance standards Rationally speaking, each category of rehabilitee has its own optimum performance standard and, therefore, comparison with the normal may often be misleading However, the information generated

socket which support the body weight are sloped, thus requiring a much larger total force than half the body's weight to be applied at right angles to the weightbearing regions of the stump, in order to give adequate support The observed increase in the test group values over the control group values, for all the physiological parameters recorded, thus should be deemed as natural in the BK amputee PTB prosthesis combination That this observed rise was not partly due to any defect in fitting, alignment and length of the prosthetic leg, was confirmed by the fact that the stump in each case was free from abrasions which are likely to result from such defects Weightbearing appeared to be distributed over the proper areas of the stump, as indicated by inspection of the stumps and noting the imprints of the stump socks on the skin of the stump

Although during the final subjective check-out examination at the clinic the departure from the normal walking performance in the test group subjects was hardly noticeable, the present ergonomic investigation revealed a 33 per cent increase of energy expenditure (converting the gross energy expenditure values per unit body weight) when compared to the controls Out of the two basic energy consuming functional components of walking on the level, that is, the static one manifested in the supportive function and the dynamic one responsible for the locomotion, the demand due to the former has already been seen to be 17 2 per cent more than the value for the control group subjects from the results of the 'standing test' That the remaining increase of 15 8 per cent over the normal subjects was due to the dynamic component (that is, for accelerating and decelerating the prosthetic leg by exerting extra motive force and power through the thigh and stump muscles, which also involved abnormal displacements and high instantaneous velocity changes of the body's centre of gravity, thereby requiring more energy to be spent than under normal circumstances) alone was evident because of the absence of other factors contributing to a rise in energy expenditure, such as, poor fit and alignment which would have shown up in several forms of stump damage Only one study on the energy expended during walking in below-knee amputees wearing prostheses has been reported in the scientific literature (Durnin & Passmore 1967) but that cannot be used for comparison because there the walking speeds were 4 2 and 5 0 km/h as against the 3 0 km/h speed chosen in the present investigation Furthermore, Durnin & Passmore's report did not mention anything about the type of prosthesis used by their test subjects

ventilations, energy expenditures and peak heart rates were measured The performance of the test subjects were compared with that of a control group consisting of sixteen normal, healthy, individuals

The percentage increases in the values of the biomechanical parameters of the test subjects, over those of the control group, were found to be justified and thus natural to the below knee amputee-PTB prosthesis system

The ergonomic study has not only yielded information regarding the biomechanical efficacy of the PTB prosthesis, but it has also shown that the amputees fitted with such prostheses can take up, without any undue extra effort and metabolic cost, industrial occupations of the moderately heavy kind

## ACKNOWLEDGEMENTS

The authors are indebted to Dr S N Sen, Vice Chancellor University of Calcutta for his constant interest and encouragement Thanks are due to Dr B B Chatterjee, Mr B N Roy and other members of the Department of Physiological and Industrial Hygiene All India Institute of Hygiene and Public Health Calcutta and also to the medical and paramedical staff of the Department of Orthopaedics, University College of Medicine (Goenka Hospital), University of Calcutta for their active help and valuable suggestions

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by the present investigation, regarding the performance of the below knee amputees fitted with PTB prostheses, can be used as a standard for comparison, for future research work in this field

The ergonomic observations have provided some very valuable information regarding the fitness level of the below-knee rehabilitees The evaluative techniques usually employed in orthopaedic and rehabilitation clinics are not capable of yielding such information The importance of ergonomic studies on the physically handicapped and the rehabilitees has been emphasized (Inman et al 1961), not only because they generate useful data about the efficacy of the assistive devices they use, but also because they enable the clinician and the rehabilitation worker to assess the possible occupations that such persons can take up as a livelihood The data available from the present investigation can be used to define the criteria whereby one could avoid imposing hazardous work loads on below-knee amputees wearing PTB prostheses

From the expenditure point of view, the heaviest natural activity studied was stair ascending For this activity, the average gross energy expenditure of the test group subjects was found to be 4 25 Kcal/min (range 3 04–6 96 Kcal/min), and they performed it without any undue excess expenditure of energy or undue discomfort, as compared to the control group subjects This value of energy expenditure falls within the group of 'moderate' exertion, in some cases *falling under* the 'heavy' exertion group, according to the classifications made by Turner (1955), Patwardhan (1960), Malhotra and his co-workers (1966) and Ramanathan and his co-workers (1967) It can, therefore, be easily concluded that the below-knee amputees fitted with PTB prostheses should be able to meet the demands of industrial occupations up to the moderately heavy grade, particularly in view of the fact in such industrial occupations, the high demands are likely to be of an intermittent nature

## SUMMARY

A below-knee amputee is generally known to achieve a close-to-normal performance level, with the patellar tendon-bearing method of stump fitting This was confirmed by an ergonomic investigation on ten below-knee amputees, fitted with PTB prostheses The test group subjects were given two static tests, two dynamic tests and one exercise tolerance test, during which their oxygen consumptions, pulmonary

ventilations energy expenditures and peak heart rates were measured The performance of the test subjects were compared with that of a control group consisting of sixteen normal healthy individuals

The percentage increases in the values of the biomechanical parameters of the test subjects over those of the control group, were found to be justified and thus natural to the below knee amputee-PTB prosthesis system

The ergonomic study has not only yielded information regarding the biomechanical efficacy of the PTB prosthesis but it has also shown that the amputees fitted with such prostheses can take up, without any undue extra effort and metabolic cost industrial occupations of the moderately heavy kind

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by the present investigation, regarding the performance of the below-knee amputees fitted with PTB prostheses, can be used as a standard for comparison, for future research work in this field

The ergonomic observations have provided some very valuable information regarding the fitness level of the below-knee rehabilitees The evaluative techniques usually employed in orthopaedic and rehabilitation clinics are not capable of yielding such information The importance of ergonomic studies on the physically handicapped and the rehabilitees has been emphasized (Inman et al 1961), not only because they generate useful data about the efficacy of the assistive devices they use, but also because they enable the clinician and the rehabilitation worker to assess the possible occupations that such persons can take up as a livelihood The data available from the present investigation can be used to define the criteria whereby one could avoid imposing hazardous work loads on below-knee amputees wearing PTB prostheses

From the expenditure point of view, the heaviest natural activity studied was stair ascending For this activity, the average gross energy expenditure of the test group subjects was found to be 4 25 Kcal/min (range 3 04–6 96 Kcal/min), and they performed it without any undue excess expenditure of energy or undue discomfort, as compared to the control group subjects This value of energy expenditure falls within the group of 'moderate' exertion, in some cases falling under the 'heavy' exertion group, according to the classifications made by Turner (1955), Patwardhan (1960), Malhotra and his co-workers (1966) and Ramanathan and his co-workers (1967) It can, therefore, be easily concluded that the below-knee amputees fitted with PTB prostheses should be able to meet the demands of industrial occupations up to the moderately heavy grade, particularly in view of the fact in such industrial occupations, the high demands are likely to be of an intermittent nature

## SUMMARY

A below-knee amputee is generally known to achieve a close to-normal performance level, with the patellar-tendon-bearing method of stump fitting This was confirmed by an ergonomic investigation on ten below-knee amputees, fitted with PTB prostheses The test group subjects were given two static tests, two dynamic tests and one exercise tolerance test, during which their oxygen consumptions, pulmonary

Acta orthop scand 46 135–140 1975

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# PATHOLOGICAL ANATOMY OF THE AGING MENISCUS

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Accepted [illegible] viii 74

Changes in the menisci of the knee joint due to the aging process have been well recognized in several studies in recent years (Chand 1972, Sideman & Siegel 1962, Smillie 1968) Horizontal lesions of the knee meniscus have been specially referred to by Smillie (1968) in his series of 3 000 cases wherein 50 per cent of the tears were horizontal, and the average age was 43 years Chand (1972), in an autopsy study of [illegible] knee joints in Scottish males and females, found a high incidence of medial meniscal tears in 14 out of 22 male knees and six out of [illegible] female knees, and lateral meniscus tears in one out of 22 male knees and two out of 22 female knees In a series of 35 knees in 31 patients over the age of 50 years, with complaints of pain and swelling over the anteromedial aspect of the knee and limitation of motion, Lidge (1970) found marked degeneration of the meniscus with fraying and shred-like areas throughout

With advancing age, the knee meniscus becomes harder and loses its elasticity The color changes to yellow in places and it becomes transluscent at the thin medial border Microscopically, there is a gradual loss of cellular elements with empty spaces and an increase in the amount of fibrous tissue in comparison to elastic tissue (Helfet 1971) These cystic areas are the start of a tear and with a torsional force imparted by the overlying femoral condyle, the superficial layers of the meniscus are sheared off from the deep one along the interface of the cystic degenerative change, thus producing a horizontal cleavage tear in the meniscus The torn meniscus infringes upon the medial condyle of the femur near the intercondylar notch, producing erosion of the articular cartilage and setting the stage for osteoarthritis (Helfet 1971) The meniscal tear can also occur in osteoarthritis secondary to articular incongruity and abnormal joint excursion (Sideman & Siegel 1962) Equally, the process of degeneration of menisci and articular

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*Key words* amputees, prosthesis

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b) Fraying (Total 65 menisci)

| | | |
|---|---|---|
| Anterior one-third | 3 | (Medial 3, lateral 0) |
| Middle third | 47 | (Medial 22 lateral 25) |
| Posterior third | 15 | (Medial 8, lateral 7) |

c) Horizontal tears (Total 39) Medial 32, lateral 7

| | | |
|---|---|---|
| Anterior one-third | 6 | (Medial 5, lateral 1) |
| Middle third | 14 | (Medial 11, lateral 3) |
| Posterior third | 19 | (Medial 2 lateral 3) |

d) Calcification (Total 8)

| | | |
|---|---|---|
| Anterior one-third | 2 | (Medial 8, lateral 0) |
| Middle third | 1 | (Medial 1, lateral 0) |
| Posterior third | 5 | (Medial 3, lateral 2) |

Autopsy specimens 21 subjects

*Articular Damage and Menisceal Tear*

| | |
|---|---|
| No articular damage | 3 patients |
| Minimum articular damage | 8 patients |
| Moderate articular damage | 7 patients |
| Severe articular damage | 3 patients |

*Age Group Distribution of Subjects with Horizontal Tears*

| | |
|---|---|
| 51–60 years | 2 |
| 61 70 years | 8 |
| 71–80 years | 6 |
| 81 90 years | 5 |

Autopsy specimens 21, cadavers 25 (Total 46)

*Sex Distribution of Subjects with Horizontal Tears*

| | | |
|---|---|---|
| Male | 12 out of 24 | (or 50 per cent) |
| Female | 9 out of 22 | (or 40 9 per cent) |

*Racial Distribution of Subjects with Horizontal Tears*

| | | |
|---|---|---|
| Black (Negro) | *15 out of 32* | (or 46 9 per cent) |
| White (Caucasian) | 6 out of 14 | (or 42 8 per cent) |

## DISCUSSION

A review of the results indicates that the degenerative changes in the menisci of knee joints progress concurrently with the degenerative

cartilage may be due to a similar etiology, i e the aging process and mechanical incongruity of the knee joint

This study was undertaken to investigate the pattern of degeneration in the menisci of the knee joint due to the aging process A detailed dissection of the knee joints in 21 autopsy specimens and 25 anatomy cadavers giving a total of 46 subjects was carried out

## MATERIALS AND METHODS

In the dissection of the knee joints the following degenerative changes in the menisci were recognized

a) Yellow areas
b) Fraying of the cartilage at both ends
   along the concave border
c) Horizontal tears in the meniscus
d) Calcified spots

The yellow areas were apparent over the surface of the menisc is as l near streal s or irregular areas The cartilage over the surface felt soft to pointed pressure and on section the area extended one third of the way through the thickness of the cartilage These areas were the earliest signs of degeneration in the cartilage

Fraying of the cartilage was noticed either along the concave border especially in the posterior third or in the anterior horn which on occasions was partly detached Multiple fine strands of fibers appeared like a brush

Horizontal tears in the meniscus always originate l on the free concave border and extended for a variable length towards the posterior horn The tear invol ed about one third of the thickness of the men scus near the middle of the cartilage altl ough it included the whole of the free concave border The tear did not extend as far laterally as the peripheral capsular border of the meniscus Long tudinally the tear extended along the yellow streal on the surface of the meniscus Detach ment of the tear from the posterior horn was not observed thoi gh when it originated anteriorly detachment from the anter or horn was seen

Calc fied spots were i lentified as wh te specl s or areas over the surface of the meniscus and gave a gritty feeling when cut across with a kn fe

## RESULTS

Total number of subjects 46

Total number of knee joints studied 90

Degenerative changes in the menisci Total knees studied 90

a) Yellow areas (Total 80 menisci)

| | | |
|---|---|---|
| Anterior one third | 7 | (Medial 3 lateral 4) |
| Middle third | 27 | (Medial 14 lateral 13) |
| Posterior third | 46 | (Medial 17 lateral 29) |

factor did not influence the final result, nor did partial or total extirpation of the meniscus or early or late postoperative weightbearing Radiological evidence of osteoarthritis before surgery was associated with unsatisfactory results

Jackson (1968) in a review of 577 knees five years after menisectomy found a higher incidence of degenerative arthritis following menisectomy Helfet (1961) has indicated that the erosion of the medial femoral condyle is associated with, and is a result of, a tear of the *anterior horn In this study, whenever such a lesion in the medial* condyle was observed, it was not an isolated lesion but there were degenerative changes in the articular cartilage in other parts of the joint Perhaps a concomitant degenerative process in the articular cartilage, added to the repeated trauma of the torn anterior horn, makes the association of these two lesions more pronounced

Wiley (1968), in a study of 114 menisci from cadavers of 30 patients found only four torn medial menisci and degenerative changes predominantly in the lateral compartment of the knee This is in contrast to the findings from this study wherein the medial meniscus and the medial compartment have been found to be more predominantly involved

## SUMMARY

In 21 autopsy subjects and 25 anatomical cadavers both knee joints were dissected extensively to find a) degenerative changes in the menisci of knee joints, especially horizontal tears and b) associated degenerative changes in the articular surfaces of the knee joint, in order to attempt a correlation between the two lesions

Thirty nine horizontal tears of the meniscus in 21 patients were found of which 32 were in the medial meniscus There was no [illegible]

[illegible] a slight preponderance

The degenerative meniscus with a horizontal tear is a part of the *overall degenerative process in* the knee joint and should be treated as such

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*Table 1 Correlation between meniscus regeneration and osteoarthritis of the knee*

| Age group | No of knee joints | Meniscus degeneration | | | | | | Osteoarthritis | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Yellow area | | Fraying | | Horizontal tears | | Fibrillation | | Erosion | | Eburn |
| | | M | I | M | L | M | L | M | L | M | L | M |
| 11–20 | [illegible] | 1 | 1 | 1 | 1 | nil | nil | nil | nil | nil | nil | nil |
| 21–30 | 2 | nil | nil | nil | nil | nil | nil | nil | nil | nil | nil | nil |
| 31–40 | 6 | nil | nil | nil | nil | nil | nil | nil | nil | nil | nil | nil |
| 41–50 | 4 | 1 | 1 | 1 | 1 | nil | nil | nil | nil | 1 | 1 | nil |
| 51–60 | 10 | 5 | 4 | 3 | 2 | 1 | nil | 4 | 1 | 4 | 1 | 1 |
| 61–70 | 28 | 14 | 16 | 13 | 6 | 11 | 2 | 22 | 11 | 24 | 11 | 17 |
| 71–70 | [illegible] | 13 | 10 | 12 | 11 | 4 | 3 | 12 | 12 | 12 | 11 | 5 |
| 81–90 | 18 | 16 | 12 | 12 | 11 | 8 | 3 | 11 | 11 | 11 | 11 | 9 |

M = Medial
I = Lateral

process in the rest of the joint Thus, symptoms produced by a degenerative meniscus, viz those produced by a horizontal tear in middle age, can only be considered and treated as an aspect of an overall degenerative joint disease rather than as an isolated lesion It is not until the sixth decade that these lesions in the menisci start appearing in appreciable numbers and seem to precede the degenerative change in the articular cartilage Later in the seventh, eighth and ninth decades, the articular damage is predominant and degenerative menisci are persistently seen along with it There is a slight preponderance of black males as far as incidence of horizontal tears in the menisci are concerned As expected, lesions in the medial meniscus predominate

In a series of 35 knees in 31 patients, Lidge (1970) found two antero medial tears, ten tears along the medial margin, nine tears in the posterior horn, four posteromedial tears and ten classified as diffuse degeneration and multiple fraying Adhesive synovitis at the site of the junction of the medial meniscus with the collateral ligament has been thought to lead to early detachment of the meniscus in the middle third Medial menisectomy has led to relief of symptoms in the majority of patients in this series However, Appel (1970), while reviewing late results of menisectomy, found that degenerative osteo arthritis occurs with a significantly higher frequency after menisectomy—10 8 per cent in operated as against 0 9 per cent in non operated cases Age at operation, longer latency period, trauma as the etiologic

Acta orthop scand 46 141–151 1975

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# TIBIAL OSTEOTOMY FOR OSTEOARTHROSIS OF THE KNEE

## A Five to Ten Year Follow up Study

P V SEAL & R N W CHAN

Accepted 15 x.74

Jackson in 1958 described tibial osteotomy as a method for relieving pain in osteoarthrosis of the knee Wardle (1962) indicated that the operation had been previously performed Tibial osteotomy is now an accepted procedure in the treatment of osteoarthrosis of the knee, although reports of its efficacy in the long term are scarce

The predominant indication for tibial osteotomy is painful deformity, with stiffness, instability and loss of function as other symptoms There have been numerous reports referring to the 70 80 per cent good early results as regards pain relief, from tibial osteotomy (Jackson & Waugh 1961 Wardle 1962, Coventry 1965, Harris & Kostuik 1970), but a follow up time beyond four years is unusual

How tibial osteotomy works remains debatable The redistribution of weightbearing stresses, the relief of soft tissue tension by the correction of deformity and alteration of local blood supply all have their proponents Analysis of the forces acting on the knee has been undertaken (Kettelkamp & Chao 1972) but whether such careful analysis to determine the angle of the osteotomy improves the results compared to merely straightening the affected limb by eye (Jackson & Waugh 1961) remains unproven

Various techniques for performing the osteotomy have been described, ball and socket at or above the tibial tubercle (Jackson & Waugh 1961 transverse below the tubercle (Wardle 1962) and a closing wedge high above the tubercle (Gariepy 1961), with or without section of the fibula Internal fixation techniques have also been described (Coventry 1965, Devas 1969) as alternatives to plaster cast immobilization post-operatively

The importance of accurate correction of the deformity has been

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*Key words* semi lunar cartilage pathology, aging, degeneration osteoarthritis

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Acta orthop scand 46, 141–151, 1975

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How tibial osteotomy works remains debatable The redistribution of weightbearing stresses, the relief of soft tissue tension by the correction of deformity and alteration of local blood supply all have their proponents Analysis of the forces acting on the knee has been undertaken (Kettelkamp & Chao 1972) but whether such careful analysis to determine the angle of the osteotomy improves the results compared to merely straightening the affected limb by eye (Jackson & Waugh 1961) remains unproven

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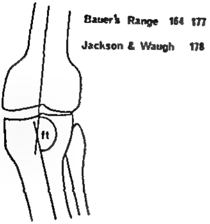
The importance of accurate correction of the deformity has been

*Figure 1 Femoro Tibial (FT) angle*




stressed (Harris & Kostuik 1970, Coventry 1973) and attention drawn to the pertinence of the Femoro Tibial (FT) angle for good results (Bauer et al 1969) The femoro tibial angle is defined as the lateral angle between the intersection of lines drawn along the axis of the femur and the tibia (Figures 1 and 5) Bauer et al (1969) found that a post operative femoro tibial angle outside the range 164°–177° was more often than not associated with a poor result In 50 healthy knees the average FT angle was 178° (Jackson & Waugh 1961)

It is the purpose of this study to establish the long term results of tibial osteotomy and to study further the relevance of the FT angle in these results

## MATERIALS AND METHODS

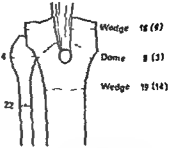
Forty seven patients (22 female and 25 male) having had tibial osteotomy for osteoarthrosis of the knee during the period 1962–1967 inclusive formed the basis of this study All but two patients (one assumed dead) were traced Eleven patients had bilateral osteotomies six during the same hospital admission and five between 1½ and 10 years after the first operation two of these second procedures being outside the limits of this study Forty six knees were in varus pre operatively and ten in valgus nine of the latter cases being women At the time of review nine patients were dead none having died earlier than 3 months post operatively Thus in all 45 knees in 37 patients were available for review and these were assessed clinically and radiologically with weightbearing films

All except five patients were in their seventh and eighth decades and the follow up distribution (Table 1) shows a fairly even spread over the 5 to 10 year period the average follow up time being 7 6 years

*Table 1 Length of follow up in years (average 7 6 years)*

| | | | | | | |
|---|---|---|---|---|---|---|
| Length of follow up (years) | [illegible] | [illegible] | 7 | 8 | [illegible] | 10 |
| Number of patients | 4 | 9 | 8 | 10 | 8 | 6 |

*Figure 2 Techniques of osteotomies (numbers in brackets indicate osteotomies with division of the fibula)*




The tibial osteotomies had been performed at various levels (Figure 2) All patients had been operated on for pain in two cases because they refused arthrodesis Both of these latter cases were graded as excellent at follow up 5 and 10 years after the operation respectively Only two osteotomies were held by internal means the remainder were managed post operatively in plaster casts

Assessment was made in terms of pain relief, mobility and function and from these three factors a final assessment was made Each factor was graded as follows

*Pain*

| | |
|---|---|
| Grade I | No pain |
| Grade II | Pain relieved by analgesics if required |
| Grade III | Pain not relieved by analgesics |

*Mobility*

| | |
|---|---|
| Grade I | $0° > 90°$ |
| Grade II | $0° - 90°$ |
| Grade III | $-5° - 60°$ |

*Function*

| | |
|---|---|
| Grade I | Normal full activities and returned to work/full activities in retirement |
| Grade II | Some limitation of activities e g use of a cane |
| Grade III | Incapacity |

*Final Assessment*

| | | |
|---|---|---|
| Excellent | 1 | All grades I |
| | 2 | One grade II |
| | 3 | No grade III |
| Good | 1 | No more than two grade II |
| | 2 | No grade III |
| Poor | 1 | All grade II |
| | 2 | One or more grade III. |

## RESULTS

### *Pain Relief*

Five to ten *years post-operatively, pain relief* was a very *striking* feature of the operation. Thirty knees had no pain and 14 had marked improvement in their level of pain which was relieved by simple analgesics. Only one patient had no pain relief and this knee was eventually arthrodesed. Seven of the 14 knees had complete relief of pain for up to 4 years and then developed increasing pain. This was usually associated with a recurrence of varus deformity (Figure 5) the average FT *angle being 189°. At review, six of these* knees were assessed as poor and the remaining one good. Five patients claimed that the contra-lateral knee had diminished function due to pain.

The duration of symptoms was more often than not longer than 2 years and in almost half the cases longer than 5 years. Of the 26 knees with symptoms less than 5 years, 23 had an excellent or good result and three poor, whereas only 12 out of 19 knees with symptoms over a period longer than 5 years had other than a poor result.

Function is closely associated with pain relief and the predominant factor causing poor results was restricted mobility (Table 2).

### *Range of Movement*

When the range of movement measured at follow up was compared with that recorded pre-operatively it was found that 34 knees had an unchanged range of movement. Coventry (1973) reported similar results.

Eight knees had a diminished range of movement of *between* 30° and 100°. The marked loss of 100° occurred in an obese lady with bilateral osteotomies not performed at the same time, who progressed well for three and a half years and then developed increasing varus deformities of both knees to FT angles of 191° and 198°, respectively, at the time of a five year review. This was associated with gross three compartment osteoarthrosis of both knees. Of the other six knees, one had a high segment deep venous thrombosis with subsequent chronic oedema of the leg, one had an ipsilateral femoral osteotomy for osteoarthrosis of the hip performed at the same operation, one had a patellectomy performed at the time of the tibial osteotomy, one had bilateral disease and osteotomies were not performed at the same time and the loss of range of movement in the remaining two knees followed bilateral tibial osteotomies performed at the same operation.

Two knees showed gains in range of movement of 50° and 45°, respectively the reason for which was not apparent One knee was arthrodesed for unrelieved pain there being no apparent technical reason for the failure in this case Restricted mobility was not a cause of concern to any of the patients in this study

*Function*

Seventeen of the 37 patients were employed at the time of operation the remainder being housewives or retired Of these 17 14 returned to their original work including farm labouring sheet metal working and long distance lorry driving The other three failed to return to work for the following reasons the first retired because of troublesome hypertension the second a 64 year old bricklayer retired a little prematurely post operatively, having obtained an excellent result, the third a 55 year old painter and decorator, with bilateral disease, had a patellectomy at the same time as his tibial osteotomy and 8 years later was assessed as poor The majority of the retired and housewives group found their function improved post operatively This functional improvement was maintained for the period of this study As expected, there is a close relationship between pain and functional activities (Table 2)

*Final Assessment* (Table 2)

27/45 Excellent
8/45 Good
10/45 Poor

*Table 2 Final assessment*

| Final assessment | Grade | Excellent | Good | Poor |
|---|---|---|---|---|
| Pain | I | 24 | 1 | 5 |
| | II | 3 | 7 | 4 |
| | III | – | | 1 |
| Mobility | I | 23 | 6 | 2 |
| | II | 4 | 2 | 3 |
| | III | – | – | 5 |
| Function | I | 27 | – | 3 |
| | II | | 8 | 6 |
| | III | – | – | 1 |
| Total | | 27 | 8 | 10 |

Objectively aceptable results 35/45

Subjectively only one patient, who subsequently came to arthrodesis, did not think the operation worthwhile Of the ten knees which were graded poor, five fell into this category because knee flexion did not exceed 60°; whereas only four had pain which was, however, controlable with analgesics Five had no pain Thus even in the group graded as objective failure half had complete pain relief The level and type of osteotomy and division of the fibula did not appear to affect the final assessment.

### *Femoro-Tibial Angle*

In this review, 26 of the excellent and good results had a femoro tibial angle range of 163°–180° The remaining nine knees in the excellent and good groups had an average FT angle of 184° with a maximum angle of 188° in one instance All the poor results were outside the range 163°–180° and all were in varus, the greatest angle being 198°, the least 184° and the average 189°

These figures confirm the findings of Bauer et al (1969) of a safe FT angle range of 164°–177° and suggest that an angle of up to 184° is compatible with an excellent result Above 184° a bad result is more than likely In other words, a varus position either by under-correction of the original varus deformity or over-correction of a previous valgus deformity is undesirable

The importance of achieving a correct final femoro-tibial angle is further emphasised by two cases which despite three compartment osteoarthrosis and a sloping joint line, maintained good results after five and ten years, respectively (Figures 3 and 4)

### *Analysis of the Poor Results*

Of the ten knees assessed as poor, all fell within a FT angle range 184°–198° with an average FT angle of 189° Four knees were under-corrected at the time of the surgery Four knees had initial pain relief for up to 4 years before pain recurred, this was associated with a recurrence of a varus deformity (Figure 5) One knee was over-corrected from valgus to varus and one knee was arthrodesed for unrelieved pain, no technical reason being obvious for the failure Two knees had other procedures performed on the same leg at the same time—one patellectomy and one upper femoral osteotomy


*Figure 3 Three compartment osteoarthrosis with subluxation and sloping joint line Good results after 5 years FT angle 180°*

*Figure 4 Three compartment osteoarthrosis with sloping joint line Good results after 10 years FT angle 180°*

*Surgical Complications*

Deep venous thrombosis 7 (At least two high segment thromboses with subsequent chronically swollen legs)
Peroneal nerve palsy – 1 (no recovery at eighteen months)
Infection 1
Pain over the fibular head – 1
Loss of correction before union – 4
Displacement of osteotomy in antero-posterior plane – 3

Objectively acceptable results 35/45

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agreement with his recommendation for osteotomy "earlier rather than later in an effort to prevent worsening and to restore more satisfactory function by lessening pain" (see Conclusions 3)

Tibial osteotomy in our series was achieved by various means In terms of the final assessment they all had similar functional results However, since the most important single factor pertinent to good long term results is adequate correction of the deformity and subsequent maintenance and, since union is most readily obtained at the upper tibial level, we would recommend the closing wedge osteotomy proximal to the patellar tendon with fixation by staples, after radiological confirmation at operation, as the method of choice (Ahlberg et al 1968 Coventry 1969, Gariepy 1961)

## CONCLUSIONS

1 Tibial osteotomy is a good pain relieving operation in osteoarthrosis of the knee, with low mortality and morbidity

2 Relief of pain can be achieved in the majority of patients and lasts up to 7½ years in most and 10 years in some A small number of patients develop pain again after a few years usually associated with recurrence or under correction of a varus deformity

3 The best results in terms of pain relief, mobility and function are obtained if the following factors are observed

   (a) The predominant symptom is pain
   (b) The duration of symptoms is less than 5 years
   (c) The pre operative mobility of the knee is greater than 90°
   (d) The deformity is corrected within a Femoro-Tibial angle range of 163° 180°

4 The long term results are not affected by

   (a) The level or type of osteotomy
   (b) Division of the fibula
   (c) The age of the patient
   (d) Bilateral osteotomies not performed at the same time

5 The range of movement was unaffected in the majority of patients A minority had diminished movement and two patients gained in range of movement

6 Function and pain relief are closely related The majority of working men even in heavy employment, returned to their original employment

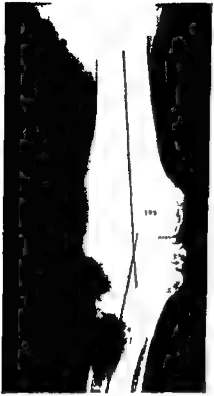

*Figure 5 Late recurrence of varus deformity Poor result after 10 years FT angle 195°*

Delayed union – 3 (two below the tibial tubercle and one above)
Damage to the popliteal and anterior tibial vessels did not occur and damage to the tibial plateau during high osteotomies was not noted

## DISCUSSION

This study confirms the findings of previous reports of early and intermediate good results following tibial osteotomy (Jackson & Waugh 1961, Wardle 1962, Coventry 1965, Bauer 1969, Harris & Kostuik 1970) Long-term reports are relatively rare The largest series to our knowledge is that of Coventry (1973) In his series of 86 osteoarthritic knees 27 were evaluated 4 to 9 years after surgery This present report of 45 knees would therefore seem to be one of the largest series with a long-term report to date It is all the more important since all but two patients (one assumed dead) were traced and assessed

Our findings correlate closely with those of Coventry (1973) We would like to emphasise especially that it is much more common to under-correct than to over-correct the deformity at osteotomy Coventry now recommends over-correction by five degrees and maintains that this effectively prevents late recurrence of deformity We are also in

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*Key words* tibial osteotomy long term follow up osteoarthrosis knee

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SUMMARY

Forty-five knees with tibial osteotomy for osteoarthrosis were studied at 5 to 10 years following surgery Twenty-seven were graded excellent eight good and ten poor

The best results were found in knees which maintained a Femoro-Tibial angle of 163°–180° whereas the poor results were associated with either under correction at operation or late recurrence of deformity The latter was closely related to pain Provided that the initial deformity is adequately corrected and maintained, tibial osteotomy for osteoarthrosis of the knee gives good results which can last up to 10 years

ACKNOWLEDGEMENTS

The authors wish to thank Mr B T O Connor for encouragement and advice the consultant staff at Oswestry for permission to study their cases Miss B I Moseley and Miss F Horne for secretarial assistance and Mr D A Foster and Mrs Machin for illustrations

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*Table 1 Sex incidence and method of treatment in 58 children with congenital clubfoot*

| | | | | | |
|---|---|---|---|---|---|
| 58 children | 37 boys | 25 unilateral | = 25 feet | Operative treatment | 21 |
| | | | | Conservative treatment | 4 |
| | | 12 bilateral | = 24 feet | Operative treatment | 20 |
| | | | | Conservative treatment | 4 |
| | 21 girls | 16 unilateral | = 16 feet | Operative treatment | 12 |
| | | | | Conservative treatment | 4 |
| | | 5 bilateral | = 10 feet | Operative treatment | 5 |
| | | | | Conservative treatment | [redacted] |

75 feet of which [redacted] operatively treated = 77 per cent operatively treated

*Table 2 Coincident deformity in eight children with congenital clubfoot*

| | |
|---|---|
| Syndactylia | 2 |
| Congenital dislocation of hip | 2 |
| Palsy of facial nerve | 1 |
| Omphalocele | 1 |
| Arthrogryposis? | 2 |
| | 8 |

thorough evaluation of the position of the foot and decided whether further treatment should be operative or conservative At the same time an X ray examination was performed. Lateral exposures were made with the foot in maximum dorsiflexion frontal exposures with the foot in neutral position

Indications for continued conservative treatment were

a) active dorsiflexion to a right angled position and passive dorsiflexion to 20° past a right angled position
b) passive correction of varus component in the hindfoot
c) passive correction of adduction of forefoot
d) passive pronation of forefoot to 20°
e) on X ray the angle between the longitudinal axes of the talus and the calcaneus in dorso plantar as well as in lateral exposures should exceed 30°

Abnormally small ossification centres in the hindfoot and severe leg atrophy were contraindications to conservative treatment

In cases where continued manipulation therapy was decided upon the child was checked by the physiotherapist two or three times weekly and by the doctor in our outpatient clinic every second or third month. The polyethylene cast was worn 24 hours a day At the age of one year the cast was changed to a night bandage of leather and when starting to walk the child was equipped with shoes with a lateral wedge The night bandage was continued up to the age of six or eight years

Acta orthop scand 46 152–160, 1975

The Department of Orthopaedic Surgery U, Rigshospitalet, Copenhagen Denmark.

# CONGENITAL CLUBFOOT

## *A Follow-up of 58 Children Treated During 1964–1969*

Knud Jorring & Leif Christiansen

Accepted 21 v 74

The object of this study is to present the results of treatment of congenital clubfoot in the Department of Orthopaedic Surgery U, Rigshospitalet, Copenhagen, during the years 1964–1969 The main purpose of the study is to clarify the cause of relapse in the operated cases

### MATERIAL

The series comprised 58 children treated for idiopathic congenital clubfoot Children with clubfoot secondary to myelomeningocele poliomyelitis or other clearly neurological or muscular disorders were not included in the present series Clubfeet which were corrected after a few weeks of manipulation were not included in this series

The sex incidence and method of treatment are illustrated in Table 1 77 per cent were treated operatively

In eight children the clubfoot was combined with other congenital deformities (Table 2) In the two patients with arthrogryposis the diagnosis was questionable as the hip and knee joints were later described as normal

### METHOD

All initial treatment was conservative Manipulation of the feet was commenced in the obstetric department as early as possible after birth and a retaining bandage of elastic flannel was applied (Thomasen 1941) In the manipulation therapy it was attempted by passive stretching of muscles tendons ligaments and joint capsules to overcome the deformity maintained by soft tissue contractures and thus normalize the relationship between the bones The manipulations were continued daily by a specially trained physiotherapist and the mother was instructed how to carry out the manipulations herself every evening

When the child was one month old a polyethylene cast (Plexidur®) was applied and corrected according to the position of the foot during the following months When the child was three months old a qualified orthopaedic surgeon made a

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| | | | | | |
|---|---|---|---|---|---|
| 58 children | 37 boys | 25 unilateral | = 25 feet | Operative treatment | 21 |
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| | | | | Conservative treatment | 4 |
| | 21 girls | 16 unilateral | = 16 feet | Operative treatment | 12 |
| | | | | Conservative treatment | 4 |
| | | 5 bilateral | = 10 feet | Operative treatment | 5 |
| | | | | Conservative treatment | [illegible] |

75 feet of which 58 operatively treated = 77 per cent operatively treated

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| | |
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thorough evaluation of the position of the foot and decided whether further treatment should be operative or conservative At the same time an X-ray examination was performed Lateral exposures were made with the foot in maximum dorsiflexion, frontal exposures with the foot in neutral position

Indications for continued conservative treatment were:

a) active dorsiflexion to a right-angled position and passive dorsiflexion to 20° past a right-angled position
b) passive correction of varus component in the hindfoot
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e) on X-ray the angle between the longitudinal axes of the talus and the calcaneus in dorso plantar as well as in lateral exposures should exceed 30°.

Abnormally small ossification centres in the hindfoot and severe leg atrophy were contraindications to conservative treatment.

In cases where continued manipulation therapy was decided upon, the child was checked by the physiotherapist two or three times weekly and by the doctor in our outpatient clinic every second or third month The polyethylene cast was worn 24 hours a day At the age of one year the cast was changed to a night bandage of leather and when starting to walk the child was equipped with shoes with a lateral wedge The night bandage was continued up to the age of six or eight years

If the above-mentioned requirements for continued conservative treatment were not fulfilled the child was admitted for surgery. The purpose of the operative procedure was to remove all the fibrotic tissue which was preventing the foot from adjusting to the neutral position and further to devide contracted capsules and ligaments and lengthen shortened tendons at the posterior and medial side of the foot. It was considered of great importance to reduce the navicular bone when displaced medially.

*Surgical technique*

The incision was made from the medial side of the tendo achilles over the tip of the medial malleolus, and along the medial side of the foot to the first metatarsophalangeal joint. The achilles tendon and the posterior tibial tendon were always lengthened. The posterior ankle capsule was divided and the peroneal tendons inspected. The deltoid ligament, the talo calcaneal ligaments and all ligaments around the navicular bone were sectioned. Occasionally, when there was marked adduction of the forefoot the abductor hallucis muscle was stripped. After this procedure a plaster cast was applied with the foot in an overcorrected position. The cast was changed after two and six weeks and removed after three months. The late postoperative treatment followed the same principles as the conservative treatment, i.e. a polyethylene cast up to the age of one year followed by a leather night bandage. Postoperative manipulations were restricted so as not to cause postoperative fibrosis. Check ups were discontinued when the child was six to eight years old.

## RESULTS

At follow-up the feet were classified into five groups according to Table 3 (Reimann 1967). 23 per cent were conservatively treated. These were all good or fair (if poor they underwent operation). The age of the children at operation is shown in Table 4. The postoperative period of observation ranged from 2½ years to 7½ years (Table 5). In one case only, the long, curved skin incision led to cutaneous necrosis, which healed in two months.

There was a high rate of reoperations. As seen in Table 3, 12 feet were classified as "poor". For this reason 11 feet were reoperated (19 per cent). The parents of one patient refused reoperation. One child was reoperated upon twice. Both reoperations were performed at another hospital. One patient was reoperated bilaterally, the rest unilaterally.

One surgeon was responsible for 43 of the operations whereas 15 operations were performed by five different surgeons. There was no difference in the frequency of reoperations in these two groups. The second operations were performed one to five years after the first, the average time being two years after the first operation. So far, the

*Table 3 Clinical results of the treatment of 75 clubfeet*

| | Conservative treatment | Operative treatment |
|---|---|---|
| *Group I* Anatomically satisfactory shape without deformity, unhindered walking active dorsal flexion to a right angled position or beyond, and active pronation to the normal position | 11 | 22 |
| *Group II* Anatomically satisfactory shape without deformities apart from easily redressable adduction of the forefoot or toes Function as in group I | 5 | 17 |
| *Group III* Anatomically considerable adduction of the forefoot which cannot be corrected manually to normal, hindfoot normal or in slight varus (0–5°) Good function with active dorsal flexion to a right-angled position, active pronation to normal or almost normal position | 1 | 6 |
| *Group IV* Anatomically slight varus and/or equinus deformity of the hindfoot as well as adduction of the forefoot Deformities not fixed Unhindered walking, active dorsal flexion and active pronation to normal or almost normal | | 1 |
| *Group V* Anatomically unsatisfactory with a fixed varus and/or equinus deformity of the hindfoot Function unsatisfactory | | 12 |

Group I + II Good   Group III + IV Fair   Group V Poor

*Table 4 The age at operation of the children with 58 clubfeet*

| Age | Feet | |
|---|---|---|
| 1–3 months | 2 | = 26 early operated |
| 4–6 months | [illegible] | |
| 7–12 months | 14 | = 32 conservative treatment unsatisfactory |
| [illegible]–18 months | 9 | |
| 19–24 months | 7 | |
| > 24 months (31 and [illegible] months) | 2 | |
| Total | 58 | |

If the above-mentioned requirements for continued conservative treatment were not fulfilled the child was admitted for surgery The purpose of the operative procedure was to remove all the fibrotic tissue which was preventing the foot from adjusting to the neutral position and further to devide contracted capsules and ligaments and lengthen shortened tendons at the posterior and medial side of the foot. It was considered of great importance to reduce the navicular bone when displaced medially

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| *Group V*<br>Anatomically unsatisfactory with a fixed varus and/or equinus deformity of the hindfoot Function unsatisfactory | | 12 |

Group I + II Good Group III + IV Fair Group V Poor

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| 19–24 months | 7 | |
| > 24 months (31 and 33 months) | 2 | |
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was not brought to regular follow up for almost a year When she was three years old she was reoperated upon bilaterally

Case 5 D S 311068 Severe left sided clubfoot

Followed from birth, operated upon at three months of age, but only lengthening of the achilles tendon and posterior capsulotomy were performed with a primary good result Relapse was obvious after 1½ years and the child was reoperated

*Case 6* F C 120168 Right sided clubfoot

The diagnosis was overlooked at birth and the child referred to our clinic when two months old Soft tissue release when five months old, usual procedure followed Immediate result was good, but reoperation indicated at the age of one year

*Case 7* K H 110767 Born on the Faroe Islands The patient came to our clinic at the age of nine months with pronounced untreated bilateral clubfeet Operated on admission and returned to the Faroe Islands Postoperative follow up neglected

Reoperated on the left side 2 years old It was noticed at operation that the amount of fibrosis usually seen in these patients was only moderate in this case Is this because she was not treated with manipulations?

*Case 8* K H 130368 Right sided congenital clubfoot Child of a single mother in poor social circumstances *Several hospital admissions for bronchitis The mother* did not understand the importance of splinting

Treated in our outpatient clinic and operated on at the age of eight months with satisfactory result Reoperated at the age of four years

*Case 9* T H 020766 Advanced bilateral congenital clubfeet with the forefoot in 90° adduction Followed from birth at our clinic At birth, suspected dislocation of the hip and at the age of four months, X ray showed subluxation of the left hip He was operated on bilaterally, and in this case the hips were included in the postoperative plaster cast

Immediately on removal of the plaster cast after three months it was recorded that the right foot was unsatisfactory Usual follow up treatment Reoperation on the right foot performed when he was five years old.

The hips were treated by a night splint for two years and then recorded as normal

*Case 10* J J H 140169 Pronounced right sided congenital clubfoot

The mother was single Soft tissue release at the age of three months with usual technique On removal of the plaster cast the foot was good Postoperative night splinting was irregular Reoperated at the age of two and a half years

*Case 11* M I A 270769 Left sided congenital clubfoot

Primary operation performed when he was six months old following the usual technique and with a primary good result. Postoperatively great difficulties in making the parents accept the necessity of the night splint and the result was poor Marked adduction of the forefoot and the heel only reached the floor with some hyperextension of the knee joint. At the age of three years and nine months reoperation was refused by the parents

## DISCUSSION

There are still divided opinions concerning the optimal primary treatment of congenital clubfoot It is generally agreed that the first treat-

*Table 5 Postoperative period of observation in 58 operated clubfeet*

| Period of observation | Feet |
|---|---|
| 2½–3 years | [illegible] |
| > 3 –4 years | 10 |
| > 4 –5 years | 16 |
| > 5 –7½ years | 27 |
| | 58 |

period of observation after the second operation has been too short to permit a final evaluation of the results No bone operations were performed

As the main purpose of the study is to clarify the causes of post operative relapse we found it of special interest to go through the case histories of the 11 "poor" cases

*Case 1* J N 030265 Severe congenital right sided clubfoot

The child lived under poor social conditions with his unmarried mother During the first year of life he had lived in institutions and the mother had the child adopted at the age of 1¼ years The usual treatment schedule was adopted soft tissue release performed when the child was four months old The immediate post operative result was very good Follow up visits to our outpatient clinic at frequent intervals were planned but the patient did not attend until after adoption

At the age of three years the child refused to wear the night splint Reoperated at the age of 4¼ years At reoperation the same procedure was followed as in the primary operation

*Case 2* M F 160166 Severe congenital right sided clubfoot

Routine therapy was adopted Soft tissue release at the age of five months On removal of the plaster cast the foot was described as good The treatment was later continued at another hospital and two reoperations have been performed there

*Case 3* A M O 231265 Left sided congenital clubfoot

The patient was born on the Faroe Islands where the primary treatment was given The patient was seen at our clinic for the first time at the age of four months There was a varus deformity of 60° adduction of 80° and equinus of 40°

A soft tissue release was made and the patient returned to the Faroe Islands Three months postoperatively there was a varus deformity of 10° adduction of 20° equinus of 10° all of which could be passively corrected to neutral position It was not possible to make regular postoperative examinations and after one year reoperation was performed

*Case 4* A W T H 240267 Congenital severe bilateral clubfeet

Mother unmarried factory worker The child spent the first six weeks of life in a paediatric department with suspected congenital heart failure This was not verified In poor condition on admission Usual manipulations not carried out Bilateral soft tissue release was performed when the child was seven months old Plaster casts removed after 2 weeks and the feet described as excellent The patient

was not brought to regular follow up for almost a year When she was three years old, she was reoperated upon bilaterally

*Case 5* D [illegible] 311068 Severe left sided clubfoot

Followed from birth operated upon at three months of age but only lengthening of the achilles tendon and posterior capsulotomy were performed with a primary good result Relapse was obvious after 1½ years and the child was reoperated.

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## DISCUSSION

There are still divided opinions concerning the optimal primary treatment of congenital clubfoot It is generally agreed that the first treat-

ment of the newborn infant with clubfoot should be manipulation (Thomasen 1941, Bertelsen 1957, Reimann 1967, Rydell & Magnusson 1970), followed by some method of splinting There are still new devices being reported (Reimann & Lyquist 1970, Rydell & Magnusson 1970).

Conservative treatment with manipulation and splinting is still advocated, either with stepwise correction and plaster casts (Kite 1963) or manipulation and splinting (Denis Browne 1934)

Early soft tissue release was described by Contargyris (1931) and later advocated by Bertelsen (1957) and Reimann (1967). We have found early operative treatment indicated in cases where conservative treatment had not led to satisfactory results by the age of three months, i e residual contractures and deformities were still present (Reimann 1967) Somppi & Sulamaa (1971) operated even earlier, preferably at the age of two weeks Our technique of soft tissue release has been described earlier (Hersh 1967, Reimann 1967, Judet 1970)

In our clinic we have succeeded in starting manipulative treatment from birth except for the three patients from the Faroe Islands and two other neglected cases.

Only a few children in our series were operated on at the age of three to four months The soft tissue release was performed at the age of seven months or older in more than half the series Surprisingly, Fjeldborg (1971) in his material found that age was of minor significance for the institution of treatment as long as it was not postponed beyond the age of six months However, Fjeldborg does not make it clear whether it was the mild cases which had the later treatment

In our series there was no difference in the results whether the children were operated on in the age of 3–4 months or later But it must be emphasized that we did operate the severe cases at an early stage and only the originally mild cases in which conservative treatment had failed were operated on at a later stage

The rate of reoperations was high (19 per cent) In the literature little information has been given concerning the incidence of reoperations in published series Reimann (1967) reported 18 reoperations on 224 feet with lengthening of the achilles tendon, but did not mention the rate of relapse in 57 feet on which medial release was performed Blockey & Smith (1966) had 11 per cent reoperations, but in their material only 186 of 316 patients were followed Somppi & Sulamaa (1971), in their series of feet operated at an early stage, found poor results in 20 per cent, but did not state the number of reoperations

We found it of special interest to make an assessment of the 11 "poor" cases in our series in which indications for reoperation were found. In six cases (1, 3, 4, 7, 8, and 10) the histories revealed severe social problems, in two other cases (6 and 11) the manipulative treatment and splinting had been more or less neglected. This pattern of social problems including parental neglect is a well known risk in the treatment of congenital clubfoot (Judet 1970). In one recurrence (case 5) the operative procedure was restricted to lengthening the achilles tendon and performing a posterior capsulotomy, no medial release was done. One patient (case 9) relapsed in spite of treatment which followed the principles of the Department. This case was complicated by the presence of a hip dislocation as well as bilateral clubfeet.

## SUMMARY

A series of 58 children with 75 idiopathic congenital clubfeet is presented. Early soft tissue release was performed in 77 per cent. The main purpose of the study was to clarify the causes of postoperative relapse. The results were poor in 12 feet, 11 (19 per cent) were reoperated. On re-evaluation of the "poor" cases we found severe social problems involved, including parental neglect.

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Reimann, I. & Lyqu[illegible] *Acta orthop.* [illegible]

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ment of the newborn infant with clubfoot should be manipulation (Thomasen 1941, Bertelsen 1957, Reimann 1967, Rydell & Magnusson 1970), followed by some method of splinting There are still new devices being reported (Reimann & Lyquist 1970, Rydell & Magnusson 1970)

Conservative treatment with manipulation and splinting is still advocated, either with stepwise correction and plaster casts (Kite 1963) or manipulation and splinting (Denis Browne 1934)

Early soft tissue release was described by Contargyris (1931) and later advocated by Bertelsen (1957) and Reimann (1967) We have found early operative treatment indicated in cases where conservative treatment had not led to satisfactory results by the age of three months, i e residual contractures and deformities were still present (Reimann 1967) Somppi & Sulamaa (1971) operated even earlier, preferably at the age of two weeks Our technique of soft tissue release has been described earlier (Hersh 1967, Reimann 1967, Judet 1970)

In our clinic we have succeeded in starting manipulative treatment from birth except for the three patients from the Faroe Islands and two other neglected cases

Only a few children in our series were operated on at the age of three to four months The soft tissue release was performed at the age of seven months or older in more than half the series Surprisingly, Fjeldborg (1971) in his material found that age was of minor significance for the institution of treatment as long as it was not postponed beyond the age of six months However, Fjeldborg does not make it clear whether it was the mild cases which had the later treatment

In our series there was no difference in the results whether the children were operated on in the age of 3–4 months or later But it must be emphasized that we did operate the severe cases at an early stage and only the originally mild cases in which conservative treatment had failed were operated on at a later stage

The rate of reoperations was high (19 per cent) In the literature little information has been given concerning the incidence of reoperations in published series Reimann (1967) reported 18 reoperations on 224 feet with lengthening of the achilles tendon, but did not mention the rate of relapse in 57 feet on which medial release was performed Blockey & Smith (1966) had 11 per cent reoperations, but in their material only 186 of 316 patients were followed Somppi & Sulamaa (1971), in their series of feet operated at an early stage, found poor results in 20 per cent, but did not state the number of reoperations

Acta orthop scand 46 161–176 1975

Department of Orthopaedic Surgery, Kanazawa University Medical School
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# CYTOKINETIC ANALYSIS OF OSTEOGENIC CELLS IN THE HEALING PROCESS AFTER FRACTURE

SHOHEI MANABE, IWAO SHIMA & SHIRO YAMAUCHI

Accepted 21.x 74

Investigating the growth of long bones, Walker et al (1972 a, b), Kemper (1971), Tonna (1958), Tonna & Cronkite (1961, 1962) have been studying chondrocytes and periosteal cells autoradiographically Tonna & Cronkite (1961) studied post-fracture cellular response autoradiographically and proposed the required conditions for the occurrence of osteogenesis

We have pursued the study of precursors of osteoblast and cartilage cells during the reintegration period after a fracture by labelling with $H^3$-Thymidine, $S^{35}$, and $H^3$-Proline and have made special studies on the process of differentiation of mesenchymal like cells and analyzed the cytokinetics of these cell systems

## EXPERIMENTAL MATERIALS AND METHODS

The femurs of 14-day-old ddN male mice were fractured subcutaneously One and 2 weeks after fracture $H^3$ Thymidine, $S^{35}$ and $H^3$ Proline were administered and the fractured parts were dissected out at certain time intervals and were examined microautoradiographically using the dipping method

### *Cumulative labelling of $H^3$ Thymidine*

$H^3$ Thymidine 1.0 $\mu$Ci/g was injected at 3 hour intervals into the abdominal cavity of the mice 1 and 2 weeks after fracture Injection was repeated up to 16 times until 45 h had elapsed. The fractured parts were dissected out 2 and 3 h after injection and every 3 h thereafter Then specimens taken within a 48 hour period were examined After fixation of the specimens in Carnoy's solution they were electrically decalcified by 10 per cent trichloroacetic acid solution and were embedded in paraffin Finally 6 $\mu$ sections were prepared

### *Uptake of $H^3$ Proline and $S^{35}$*

$H^3$ Proline 2.0 $\mu$Ci/g was injected into the abdominal cavities of a group of mice 1 and 2 weeks after fracture and likewise $S^{35}$ 1.0 $\mu$Ci/g was injected into another

Somppi, E. & Sulamaa, M. (1971) Early operative treatment of congenital clubfoot. *Acta orthop. scand.* 42, 513–520.
Thomasen, E. (1941) Der angeborene Klumpfuss *Acta orthop scand* 12, 33-100

*Key words:* clubfoot; therapy

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# CYTOKINETIC ANALYSIS OF OSTEOGENIC CELLS IN THE HEALING PROCESS AFTER FRACTURE

SHOHEI MANABE, IWAO SHIMA & SHIRO YAMAUCHI

Accepted 22.x.72

Investigating the growth of long bones, Walker et al. (1972 a, b), Kemper (1971), Tonna (1961), Tonna & Cronkite (1961, 1962) have been studying chondrocytes and periosteal cells autoradiographically. Tonna & Cronkite (1961) studied post-fracture cellular response autoradiographically and proposed the required conditions for the occurrence of osteogenesis.

We have pursued the study of precursors of osteoblast and cartilage cells during the reintegration period after a fracture by labelling with $H^3$-Thymidine, $S^{35}$, and $H^3$-Proline and have made special studies on the process of differentiation of mesenchymal-like cells and analyzed the cytokinetics of these cell systems.

## EXPERIMENTAL MATERIALS AND METHODS

The femurs of 15-day-old ddN male mice were fractured subcutaneously. One and 2 weeks after fracture, $H^3$-Thymidine, $S^{35}$ and $H^3$-Proline were administered and the fractured parts were dissected out at certain time intervals and were examined autoradiographically using the dipping method.

*Cumulative labelling of $H^3$-Thymidine*

$H^3$-Thymidine 1.0 $\mu$Ci/g was injected at 3-hour intervals into the abdominal cavity of the mice 1 and 2 weeks after fracture. Injection was repeated up to 11 times, until 45 h had elapsed. The fractured parts were dissected out 2 and 3 h after injection and every 3 h thereafter. Then, specimens taken within a 48-hour period were examined. After fixation of the specimens in Carnoy's solution they were electrically decalcified by 10 per cent trichloroacetic acid solution and were embedded in paraffin. Finally, 6 $\mu$ sections were prepared.

*Uptake of $H^3$-Proline and $S^{35}$*

$H^3$-Proline 2.0 $\mu$Ci/g was injected into the abdominal cavities of a group of mice 1 and 2 weeks after fracture and likewise $S^{35}$ 1.0 $\mu$Ci/g was injected into another

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# CYTOKINETIC ANALYSIS OF OSTEOGENIC CELLS IN THE HEALING PROCESS AFTER FRACTURE

SHOHEI MANABE IWAO SHIMA & SHIRO YAMAUCHI

Accepted 21 x 74

Investigating the growth of long bones Walker et al (1972 a, b), Kemper (1971) Tonna (1958), Tonna & Cronkite (1961, 1962) have been studying chondrocytes and periosteal cells autoradiographically Tonna & Cronkite (1961) studied post fracture cellular response autoradiographically and proposed the required conditions for the occurrence of osteogenesis

We have pursued the study of precursors of osteoblast and cartilage cells during the reintegration period after a fracture by labelling with H³ Thymidine S³⁵ and H³ Proline and have made special studies on the process of differentiation of mesenchymal like cells and analyzed the cytokinetics of these cell systems

## EXPERIMENTAL MATERIALS AND METHODS

The femurs of 14 day old ddN male mice were fractured subcutaneously One and 2 weeks after fracture H³ Thymidine S³⁵ and H³ Proline were administered and the fractured parts were dissected out at certain time intervals and were examined microautoradiographically using the dipping method

*Cumulative labelling of H³ Thymidine*

H³ Thymidine 1 0 μCi/g was injected at 3 hour intervals into the abdominal cavity of the mice 1 and 2 weeks after fracture Injection was repeated up to 16 times until 45 h had elapsed The fractured parts were dissected out 2 and 3 h after injection and every 3 h thereafter Then specimens taken within a 48 hour period were examined After fixation of the specimens in Carnoy's solution they were electrically decalcified by 10 per cent trichloroacetic acid solution and were embedded in paraffin Finally 6 μ sections were prepared

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$$\text{Mitotic Index (MI)} = 100 \times \frac{Mt}{Gt}$$

Using these values presynthetic resting time ($Gt_1$) is calculated by the following equation

$$Gt_1 = Gt - (Gt_2 + Mt + St)$$

## EXPERIMENTAL RESULTS

### *Uptake of H³ Proline in the fractured parts*

*One week after fracture* Five min after the injection of H³ Proline the grains were observed in osteoblasts and proliferative cartilage cells and a time wise change of the number of grains in each cell was noticed After 2 h the average number of grains in the cells decreased as shown in Figure 1 Similar findings were observed in hypertrophic cartilage cells As indicated in Figure 1 the average intracellular number of grains reached its maximum and thereafter grains were gradually discharged outside the cells to the matrix Two hours after injection it was observed that grains had migrated into the matrix The number of grains was 2600/mm² in the matrix of the osteoid 670/mm² in the proliferative cartilage and 480/mm² in the matrix of the hypertrophic cartilage It was characteristic for the matrix of the osteoid that grains were densely lined in a belt form at the surface of the osteoid (Figure 2)

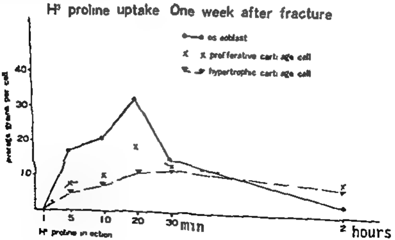


*Figure 1 The intracellular number of grains of H³ Proline per cell*

group by the same method The fractured parts were dissected out at intervals of 1, 5, 10, 20, 30 min and 2 h Using the same method as with the $H^3$-Thymidine group, 8 $\mu$ paraffin sections were prepared

*Time-wise changes of $H^3$-Thymidine uptake*

After producing fractures in the mice by the same method as above, $H^3$ Thymidine 1 0 $\mu$Ci/g was injected into their abdominal cavities on the 3rd 5th, 7th 10th and 14th days after fracture The fractured part was dissected out 2 h after such injection and fixed in Carnoy's solution The time-wise changes after fracture were observed using the 2-hour Labelling Index

*Dipping method*

DNA staining of these prepared sections was carried out by the Feulgen reaction Thereafter the specimens were subjected to dipping, using 'Sakura emulsion NR-$M_2$ for autoradiography" The specimens were then placed in a sealed box with a tube containing silica gel and exposed for 30 days at 4° C. After the specimens were developed they were studied microscopically

*Measurement of precursor-uptake in matrix*

Uptake of $H^3$-Proline and $S^{35}$ into cartilage and osteoid matrix was measured as the number of grains per unit area Using a micrometer and gradated viewing lens the zone line was set at each detection section and the number of grains contained in each zone was counted The number of grains per unit area of matrix (1 mm²) was calculated from this information

*Analysis of cumulative labelling*

As for the test *in vivo*, relative cumulative results are obtained by injecting $H^3$ Thymidine at 3 hourly intervals Labelled cells were counted with the specimens obtained by dipping and the percentage of labelled cells (P L.C ) was calculated When time is taken as the abscissa and the P L C is plotted on the ordinate axis as indicated in Figure 8, a linear increase of P L C is shown on the graph When the distance between point 'b' on the X axis, which represents the point where the above mentioned straight line reaches 100 per cent, and point "c", at which the extension of the said straight line cuts through the X axis, is measured the generation time (Gt) is obtained However it is a well known fact that the P L.C *in vivo*' never reaches 100 per cent The result shown in Figure 9 suggests that there exists (100 d) per cent of undivided cells The value "a" of P L C at time $t = 0$ indicates a Labelling Index (L I ) but DNA synthetic time (St) satisfies the equation

$$C \quad Gt = 100 \times \frac{St}{Gt} \quad 100$$

Therefore it is understood that St is represented by the measured value of "c' Postsynthetic resting time or premitotic time ($Gt_2$) is the time from injection of $H^3$ Thymidine to the time of the first appearance of labelled mitotic cells Thus the mitotic time (Mt) can be calculated from the equation

$$\text{Mitotic Index (M.I.)} = 100 \times \frac{Mt}{Gt}$$

Using these values, presynthetic resting time ($Gt_1$) is calculated by the following equation

$$Gt_1 = Gt - (Gt_2 + Mt + St)$$

## EXPERIMENTAL RESULTS

### *Uptake of $H^3$-Proline in the fractured parts*

*One week after fracture* Five min after the injection of $H^3$-Proline, the grains were observed in osteoblasts and proliferative cartilage cells and a time-wise change of the number of grains in each cell was noticed After [illegible] h, the average number of grains in the cells decreased as shown in Figure 1 Similar findings were observed in hypertrophic cartilage cells As indicated in Figure 1, the average intracellular number of grains reached its maximum, and thereafter grains were gradually discharged outside the cells to the matrix Two hours after injection, it was observed that grains had migrated into the matrix The number of grains was 2600/mm² in the matrix of the osteoid, 670/mm² in the proliferative cartilage and 480/mm² in the matrix of the hypertrophic cartilage It was characteristic for the matrix of the osteoid that grains were densely lined in a belt form at the surface of the osteoid (Figure 2)

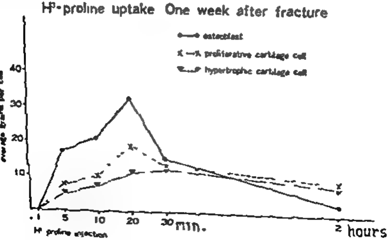


*Figure 1 The intracellular number of grains of $H^3$-Proline per cell.*

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After producing fractures in the mice by the same method as above $H^3$ Thymidine 1 0 $\mu$Ci/g was injected into their abdominal cavities on the 3rd 5th 7th 10th and 14th days after fracture The fractured part was dissected out 2 h after such injection and fixed in Carnoy s solution The time wise changes after fracture were observed using the 2 hour Labelling Index

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$$C \quad Gt = 100 \times \frac{St}{Gt} \quad 100$$

Therefore it is understood that St is represented by the measured value of c Postsynthetic resting time or premitotic time ($Gt_2$) is the time from injection of $H^3$ Thymidine to the time of the first appearance of labelled mitotic cells Thus the mitotic time (Mt) can be calculated from the equation

cartilage cells, grains were first observed 30 min after injection By this time, however, the grains in other cellular systems had already migrated into the matrix of the osteoid Two hours later, the average number of grains in the matrix of the osteoid was 1100/mm², lined in a belt form, 85/mm² in the proliferative cartilage zone and 53/mm² in the hypertrophic cartilage zone

*Uptake of $S^{35}$ in the fractured parts*

***One week after fracture*** Five min after administration of $S^{35}$, labelling was observed in the matrix of cartilage and proliferative cartilage cells and, 10 min later, intracellularly in the hypertrophic cartilage cells Thirty min later, the intracellular number of grains reached a maximum but even 2 h later, the grains were still observed in both cartilage cell systems (Figure 4) However, as early as 20 min after injection of $S^{35}$, grains from the cells migrated to the matrix of the cartilage After a further 30 min, the migration became quite vigorous and 2 h later, the average number of grains was 1960/mm² in the matrix of the proliferative zone and 620/mm² at the hypertrophic zone In spite of the fact that no grains were observed in osteoblasts during this 2 hour period, an average number of grains of 260/mm² was found in the osteoid matrix 2 h later

***Two weeks after fracture*** The grains first appeared in the matrix

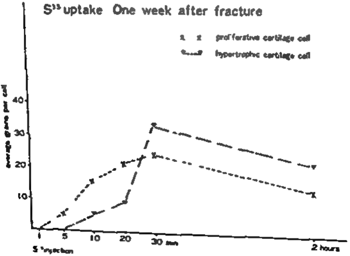



*Figure 4 The average number of grains of $S^{35}$ per cell*

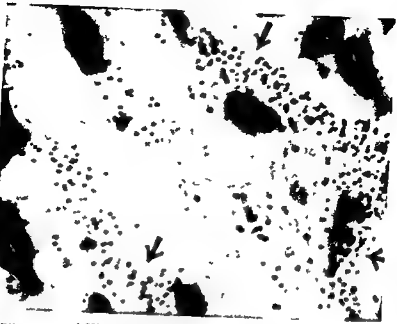


*Figure 2. Many grains of $H^3$-Proline are densely lined in a belt form at the surface of the osteoid One week after fracture and 2 h after the injection of $H^3$-Proline × 1000.*

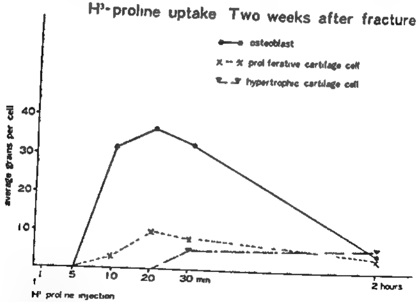



*Figure 3 The average number of grains of $H^3$ Proline per cell*

*Two weeks after fracture:* Ten min after injection, grains appeared in osteoblasts and in the proliferative cartilage cells As shown in Figure 3, the intracellular number of grains reached its maximum 20 min after injection for both systems In the case of hypertrophic

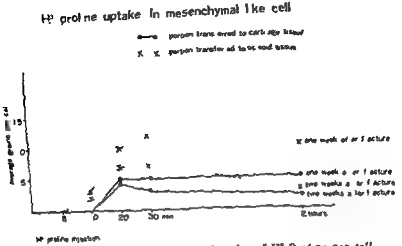



*Figure 6 The average number of grains of H³ Proline per cell*

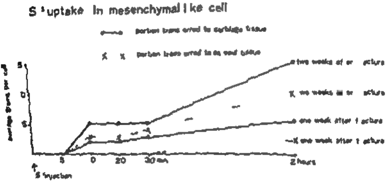



*Figure 7 The average number of grains of S³⁵ per cell*

*Analysis of cytokinetics*

Analysis of the cytokinetics was made by cumulative labelling using H³ Thymidine on three cellular systems viz mesenchymal like cells cartilage cells and osteoblasts

*Analysis one week after fracture* In the case of mesenchymal like cells 2 hours after starting the administration of H³ Thymidine the P L C was 15 per cent as illustrated in Figure 10 and thereafter as time went by the P L C increased almost in a straight line reaching 90 per cent in 21 h and thereafter the curve formed a plateau From Figure 10 it is known that one week after fracture Gt was 23 h and St

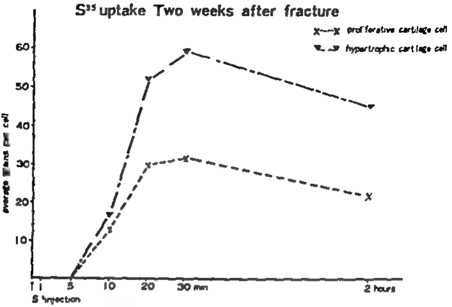



*Figure 5 The average number of grains of $S^{35}$ per cell*

of the cartilage 5 min after injection of $S^{35}$ and 10 min later intracellular grains were observed As indicated in Figure 5, 30 min after injection the intracellular number of grains reached a maximum in both the proliferative cartilage cells and the hypertrophic cartilage cells Even after 2 h a considerable number of grains was still observed Migration of grains into the cartilage matrix started 20 min after injection of $S^{35}$, and after 2 h the average number of grains in the proliferative zone had increased to 1970/mm² while that in the hypertrophic zone was 1120/mm² Also in the matrix of the osteoid, 820 grains/mm² were observed but there was no uptake of $S^{35}$ in osteoblasts during the observation period

### *Uptake of $H^3$-Proline and $S^{35}$ in mesenchymal-like cells*

Mesenchymal like cells which appeared after fracture gave an image suggesting morphological transformation of mesenchymal-like cells into the osteoid tissue or the cartilage tissue At both zones, the uptake of $H^3$-Proline was observed, but intracellular uptake of $H^3$-Proline and $S^{35}$ in the two transitional zones was different quantitatively Thus, as regards mesenchymal-like cells in the region where transformation into osteoid tissue was taking place, a marked uptake of $H^3$-Proline was observed whereas the same transitional zone to cartilage tissue indicated an even more marked intracellular uptake of $S^{35}$ (Figure 7)

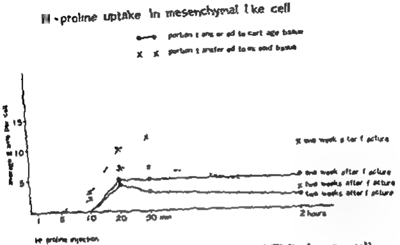
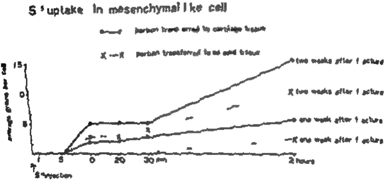



*Figure 6 The average number of grains of H³ Proline per cell*

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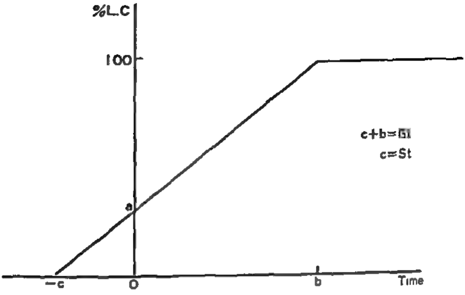



*Figure 8 Analysis of cumulative labelling method*

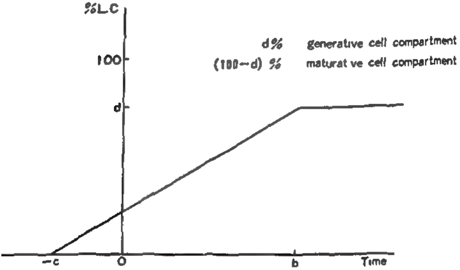



*Figure 9 Cumulative labelling method and growth fraction The value of d shows growth fraction*

was 2 h Since labelled mitoses were observed 2 h after the start of $H^3$-Thymidine administration (Figure 11), Gt. was 2 h while the mitotic Index (M I ) was 0 07 Therefore Mt was known to be about 1 6 h Accordingly, from the equation, it was also known that $Gt_1$ was about 17 4 h

Next, the P L C of osteoblasts was 14 per cent at 2 h after ad-

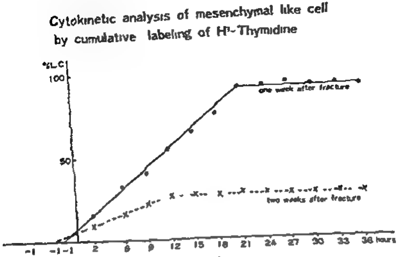
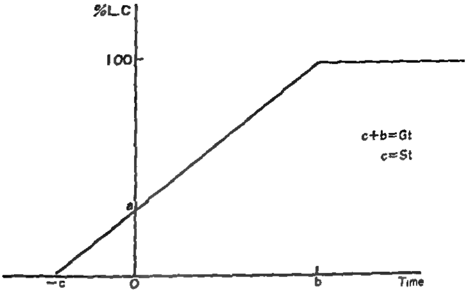



*Figure 10*

*Figure 11 Labelled mitosis of mesenchymal like cell is observed One week after fracture and 2 h after starting the administration of H³-Thymidine × 1000*

ministration of H³-Thymidine, and thereafter it increased almost linearly, reaching 72 per cent in 18 h. Thereafter, the curve formed a plateau as indicated in Figure 12 From Figure 12 it is known that Gt was 20 h and St was 2 h Since the time span from the start of the administration of H³-Thymidine to the initial appearance of labelled

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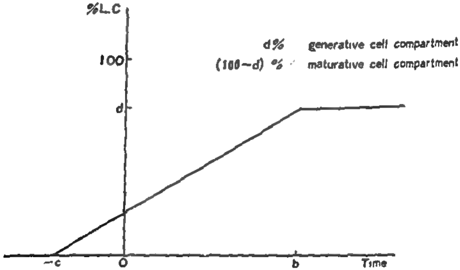


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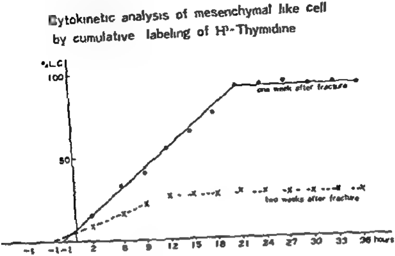


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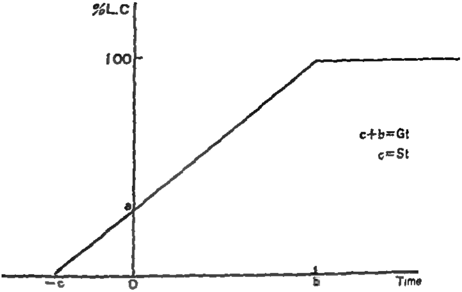


*Figure 8 Analysis of cumulative labelling method*

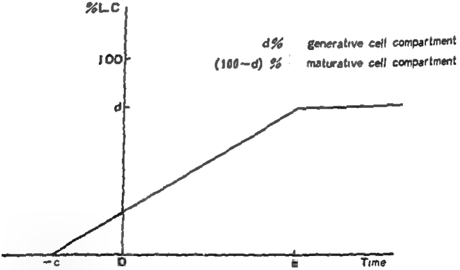


*Figure 9 Cumulative labelling method and growth fraction The value of d shows growth fraction*

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Next, the P L C of osteoblasts was 14 per cent at 2 h after ad

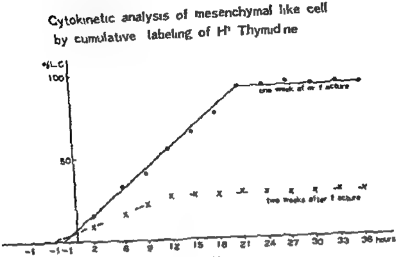


*Figure 10*

*Figure 11 Labelled mitoses of mesenchymal like cell II observed One week after fracture and 2 h after starting the administration of H³ Thymidine × 1000*

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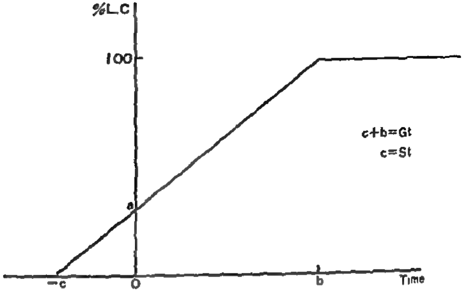
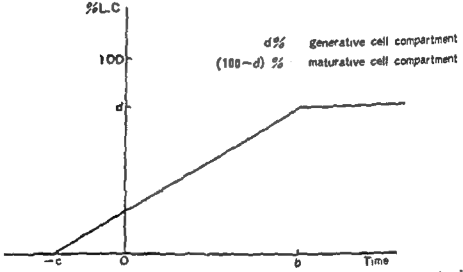



*Figure 8 Analysis of cumulative labelling method*

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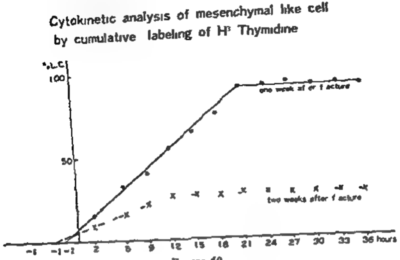


*Figure 10*

*Figure 11 Labelled mitosis of mesenchymal like cell is observed One week after fracture and 2 h after starting the administration of $H^3$ Thymidine × 1000*

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Cytokinetic analysis of osteoblast
by cumulative labeling of H³-Thymidine

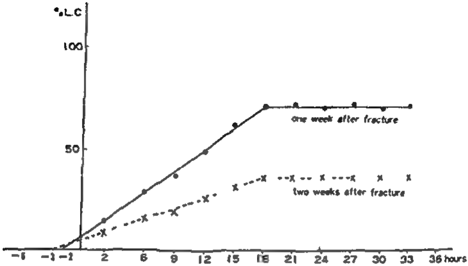



*Figure 12*

Cytokinetic analysis of proliferative cartilage cell
by cumulative labeling of H³-Thymidine

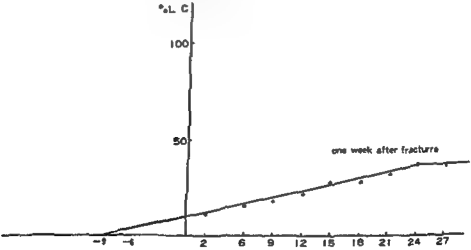



*Figure 13*

mitoses was 6 h, $Gt_2$ was 6 h Since M I was 0 02, Mt was 0 4 h Accordingly, from the foregoing equation, $Gt_1$ should be 11 6 h As for the cartilage cells, DNA synthesis was observed only with proliferative cartilage cells These labelled proliferative cartilage cells were able to be observed adjacent to the group of labelled mesenchymal-like cells and their P L C reached 12 per cent after the administration of H³-

Thymidine and thereafter increased up to 38 per cent in 24 hours Subsequently it remained in the range of 36–38 per cent to form a plateau (Figure 13) From Figure 13, it is known that Gt was 33 h and St was 9 h However, since no mitosis was observed with these cells it was impossible to obtain Mt, Gt, and Gt₂

*Analysis 2 weeks after fracture* The P L C of mesenchymal-like cells increased linearly after the start of the administration of $H^3$-Thymidine as indicated in Figure 10, and reached 25 per cent after 12 h Thereafter the curve formed a plateau From this Figure, it is known that Gt was 15 h and St was 3 h Since labelled mitoses first appeared 2 h later, $Gt_2$ was thus 2 h From M I (0 04) Mt was calculated to be about 0 6 h, from which $Gt_1$ was calculated at about 9 4 h

The P L C of osteoblasts increased linearly after the start of the administration of $H^3$-Thymidine as indicated in Figure 12 Eighteen hours later, it reached 31 per cent and thereafter the curve formed a plateau From Figure 12, it is known that Gt of osteoblast 2 weeks after fracture was 21 h and St was 3 h Since labelled mitoses first appeared at [illegible] h, $Gt_2$ was 6 h Since M I was 0 02, Mt was calculated to be 0 4 h and consequently $Gt_1$ was 11 6 h In the case of the proliferative cartilage cells no labelled cells were found within 9 h of the start of the administration of $H^3$-Thymidine but even 12 h later, P L C indicated 11 per cent with no further increase Consequently, cytokinetic analysis was impossible

*Growth fraction of the aforementioned cellular systems* When the P L C curve reaches 100 per cent and then forms a plateau in the cumulative labelling of a cellular group, the growth fraction should be 1 0 If so, it is considered to be an almost uniform group of proliferative cells (Figure 8) However, as shown in Figure 9, if the P L C of $H^3$ Thymidine reaches only up to "d per cent", it means that the amount of proliferative cells in that particular cellular group is only d per cent and therefore the growth fraction is $\frac{d}{100}$ Based on the above concept, it is known that for mesenchymal-like cells [illegible] ... cells, the growth fraction 1 week after fracture was 38 per cent but that 2 weeks after was unavailable due to the reasons given above

*Time wise change of P L C after fracture (2 hour Labelling Index)* On the 3rd day after fracture the proliferation of mesenchymal-like

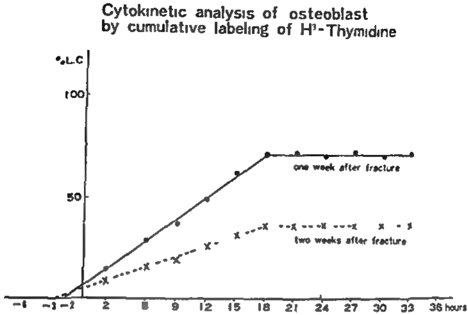
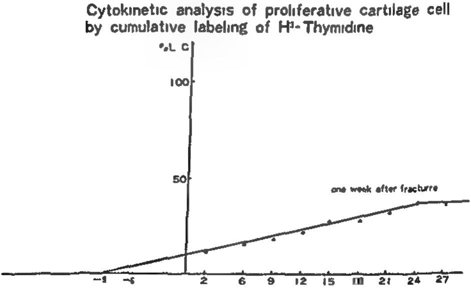



*Figure 12*

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*Time wise change of P.L C after fracture (2 hour Labelling Index)* On the 3rd day after fracture the proliferation of mesenchymal like

cells was observed in the fractured part, starting at the outer periosteum region The P L C of mesenchymal-like cells at 2 h after administration of $H^3$-Thymidine indicated 18 per cent On the 5th day after fracture the P L C of mesenchymal-like cells indicated 16 per cent Labelled cartilage cells were found adjacent to the region where labelled mesenchymal-like cells existed and their P L C was 24 per cent On the 7th day after fracture, formation of osteoid was observed and the percentage of labelled osteoblasts was 11 per cent while that of labelled mesenchymal-like cells was 12 per cent Labelling of cartilage cells was also 12 per cent In the cartilagenous tissue the grains were found only in the proliferative cartilage cells which appeared to be transformed from the mesenchymal-like cells On the 10th day after fracture, the P L C of osteoblasts was 10 per cent and that of mesenchymal-like cells was 11 per cent, but no labelling of cartilage cells was found On the 14th day, the P L C of mesenchymal-like cells was 9 per cent and that of osteoblasts was 8 per cent DNA synthesis was observed for both of these cells but no labelling was seen in the cartilage cells

## DISCUSSION

In 1962, Bassett (1962) proposed the concept of the differentiation of pluripotential cells in connection with the genesis of osteogenic and chondrogenic cells and proved that there existed the process of mesoderm → primitive fibroblast → milieu → cartilage (chondroblast), bone (osteoblast) and fibrous tissue (collagenoblast) by *in vitro* experiments using a chick embryo tibia Urist et al (1965) said that mesenchymal-like cells might form cartilage or fibrous or osteoid tissue according to the milieu and that the environmental condition was one of the key elements which determined the direction of differentiation Tonna & Cronkite (1961) administered $H^3$-Thymidine to Swiss Albino mice and observed the change of the prognosis of a fractured femur in terms of Labelling Index As a result, they found that in the fractured region, proliferation of mesenchymal-like cells was quite strong and originated from the periosteum These experiments were intended to prove that mesenchymal-like cells would differentiate into osteoblasts under certain conditions and stimuli

However, no detailed examinations have so far been made in regard to the cytokinetics of osteogenic cells in the process of recovery after fracture Nor have there been any reports on experiments to indicate

*Table 1 Cell cycle and growth fraction of mesenchymal like cell and osteoblast at 1 and 2 weeks after bone fracture*

| | | Gt | St | Mt | $Gt_1$ | $Gt_2$ | Growth fraction |
|---|---|---|---|---|---|---|---|
| Mesenchymal like cell | One week after fracture | 23 h | 2 | 1 6 | 17 4 | 2 | 0 9 |
| | Two weeks after fracture | 15 h | 3 | 0 6 | 9 4 | 2 | 0 25 |
| Osteoblast | One week after fracture | 20 h | 2 | 0 4 | 11 6 | 6 | 0 72 |
| | Two weeks after fracture | 21 h | 3 | 0 4 | 11 6 | [illegible] | 0 31 |

the rate of transformation into $G_0$ period cells and functional cells (F cell) in the cell cycle of osteogenic cells

In this experiment, the first result obtained was that mesenchymal-like cells and osteoblasts had their own cell cycles but that these cycles might change in the stages after the fracture Mesenchymal like cells in particular indicated the remarkable changes of such cycles Generation time one week after fracture was 23 h but 2 weeks later it [illegible] of Gt was completely unexpected because Gt had been estimated to be shorter in the earlier period when cell proliferation was more vigorous As to osteoblasts, unlike the case of mesenchymal like cells, slight prolongation of Gt and St was observed 2 weeks after fracture, as indicated in Table 1 What was common in these two cell systems was the finding that the angle of slope of the upward going line of the P L M indicated in Figures 10 and 12 became smaller 2 weeks after fracture Such a reduction of the angle of slope means a prolongation of St and a decrease of growth fractions

The second finding obtained in this experiment was the change of the growth fractions In the case of mesenchymal like cells the growth fraction changed from 0 9 to 0 25 in the period from 1 to 2 weeks after fracture and a radical decrease of the generative cell compartment was observed Seventy five per cent of these mesenchymal like cells were considered as the functional cells and $G_0$ period cells The former will

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| | | Gt | St | Mt | $Gt_1$ | $Gt_2$ | Growth fraction |
|---|---|---|---|---|---|---|---|
| Mesenchymal like cell | One week after fracture | 23 h | 2 | 1.6 | 17.4 | 2 | 0.9 |
| | Two weeks after fracture | 15 h | 3 | 0.6 | 9.4 | 2 | 0.25 |
| Osteoblast | One week after fracture | 20 h | 2 | 0.4 | 11.6 | 6 | 0.72 |
| | Two weeks after fracture | 21 h | 3 | 0.4 | 11.6 | 6 | 0.31 |

the rate of transformation into $G_0$ period cells and functional cells (F cell) in the cell cycle of osteogenic cells

In this experiment, the first result obtained was that mesenchymal-like cells and osteoblasts had their own cell cycles but that these cycles might change in the stages after the fracture Mesenchymal like cells in particular indicated the remarkable changes of such cycles Generation time one week after fracture was 23 h but 2 weeks later it shortened to 15 h and such shortening was mainly caused by shortening of the duration of $Gt_1$ On the other hand St indicated a slight prolongation (Table 1) This shortening of Gt was completely unexpected because Gt had been estimated to be shorter in the earlier period when cell proliferation was more vigorous As to osteoblasts, unlike the case of mesenchymal like cells, slight prolongation of *Gt* and St was observed 2 weeks after fracture, as indicated in Table 1 What was common in these two cell systems was the *finding that* the angle of slope of the upward going line of the P L C indicated in Figures 10 and 12 became smaller 2 weeks after *fracture* Such a reduction of the angle of slope means a prolongation of St and a decrease of growth fractions

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after administration suggest that proliferation of mesenchymal like cells occurs first and then follows the process of mesenchymal like cells → cartilage cells followed by the process of mesenchymal like cells → osteoblasts

The last but quite interesting point is whether or not there is the process of transformation from chondrocytes to osteoblasts According to Bently & Greer (1970), it is said that chondrocyte in epiphyseal plate is not the precursor of osteoblast in the process of enchondral ossification In the present experiment

(1) No labelling was noticed in degenerative cartilage cells during the 36 h period of observation after cumulative labelling of $H^3$ Thymidine

(2) Increase of P L C of osteoblasts was linear and did not result in double phase lines having an upward inclination on a graph

(3) The two cell systems of osteoblasts and cartilage cells were functionally different

From the above three findings it was considered that the process of transformation from chondrocytes to osteoblasts was unlikely to occur at cellular level but on the other hand it was proven that in spite of no intracellular uptake of $S^{35}$ in osteoblast the grains were observed in the matrix of the osteoid and if so cartilage tissue would be significant in the mechanism of ossification

## CONCLUSION

As the result of cytokinetic analysis of osteogenic cell at the time of reintegration after experimentally administered bone fractures in mice the following findings were obtained

1) Gt of mesenchymal like cells 1 week after fracture was 23 h but that 2 weeks later was 15 h This shortening of Gt was due to the shortening of $Gt_1$ Gt of osteoblasts one week after was 20 h and that 2 weeks after was 21 h This prolongation of Gt was due to the prolongation of St Despite the fact that Gt of mesenchymal like cells 2 weeks after fracture was shortened St indicated prolongation

2) Both mesenchymal like cells and osteoblasts indicated a reduction of growth fractions 2 weeks later From these facts it is considered that in the reintegration of the fracture these proliferative cells

differentiate, as stated later, in two directions, namely osteoblast and cartilage cell, whereas the latter is thought to transform into the resting mesenchymal-like cells The same mechanism is likely with osteoblasts and in the light of the change of growth fraction from 0 72 to 0 31 it may be possible that there are cell populations which transform into osteocyte and resting non-dividing osteoblasts From these facts, it is supposed that each cell system controls the decrease of its own generative cell compartment depending upon the degree of requirement of the reintegration of a fracture

The third interesting finding was the uptake test with $S^{35}$ and $H^3$ Proline This test revealed that mesenchymal-like cells had the potential to develop into osteoblasts and cartilage cells The mesenchymal like cells indicating transition into osteoblasts (osteoid) had a greater uptake of $H^3$-Proline while those indicating transition into cartilage cells (cartilage tissue) had a greater uptake of $S^{35}$ This fact suggests that mesenchymal-like cells potentially have two functional natures and they are pluripotential in that they can differentiate into either osteoblasts or chondroblasts The osteoblasts which were differentiated from mesenchymal-like cells indicated vigorous intracellular $H^3$-Proline uptake, and in a short time (within 2 h) grains of $H^3$-Proline were discharged into the matrix of the osteoid As stated above, osteoblasts are evidently the functional cells, but osteoblasts are not only a result of cellular flux from mesenchymal-like cells but also function as generative cells in the succeeding system from osteoblasts to osteocytes On the other hand, cartilage cells indicated strong uptake of $S^{35}$, but they discharged $S^{35}$ into the matrix of the cartilage tissue in a short time and thus fulfilled an important role in the formation of the matrix of the cartilage However, labelling of $H^3$-Thymidine started from *proliferative cartilage cells only, and DNA synthesis of cartilage cells* occurred only in the region adjacent to mesenchymal-like cells showing high P L C At one week after fracture, the generation time of proliferative cartilage cells was 33 h and St was 9 h, which were longer than those of their cell systems In addition, their growth fraction was 0 38 which was lower than that of other cell systems From these facts it may be concluded that 1 week after fracture, this cell system is not positively concerned with the reintegration of the fracture The fact that no increase of P L C was observed 2 weeks after fracture would support the above conclusion

The findings obtained on the 3rd, 5th, 7th, 10th and 14th days after fracture in regard to $H^3$-Thymidine uptake of various cell systems 2 h

after administration suggest that proliferation of mesenchymal like cells occurs first and then follows the process of mesenchymal-like cells → cartilage cells followed by the process of mesenchymal-like cells → osteoblasts

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2) Both mesenchymal like cells and osteoblasts indicated [illegible] of growth [illegible] that in [illegible]

control their own growth fractions according to the necessity of repair of the fractured part

3) It was argued that chondrocytes originated from mesenchymal like cells but should not be the precursors of osteoblasts
4) It was shown that mesenchymal-like cells must have the potential to differentiate into either osteoblasts or chondrocytes
5) Mesenchymal-like cells are the precursors of osteoblasts and the latter are the precursors of osteocytes, but mesenchymal like cells and osteoblasts have their own respective cell cycles
6) It was argued that the relation between $S^{35}$ uptake by the matrix of the osteoid and chondrocytes as functional cells should be studied in relation to the role played by cartilage tissue in the mechanism of ossification

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*Key words* cytokinetic osteogenic fracture

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Acta orthop scand. 46 177–184 1975

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# EFFECT OF VENOUS STASIS ON LONGITUDINAL BONE GROWTH IN THE RABBIT

Lars Ingvar Hansson Anders Stenström & Karl-Göran Thorngren

Accepted 21 xi 74

The effect of so-called growth stimulating operations on the increase in length of bones has been the subject of many clinical and experimental investigations (Goff 1960 Taillard & Morscher 1965, Hansson 1967, Sunden 1967) These operations have been performed on the bone, on the vascular system, or on the nervous system

Since the latter part of the 19th century, various investigations have been made to find out the effect of venous stasis on bone growth Venous stasis has usually been induced by ligation or by external compression by a tourniquet Judging from the experimental investigations, the growth stimulating effect of venous stasis is questionable Stimulation of longitudinal bone growth has been described by some authors (Borel 1922 Bergmann 1931, Kishikawa 1936, Servelle 1948, Hutchison & Burdeaux 1954, Colt & Iger 1963), whereas others have been unable to demonstrate any such effect with certainty (Wu & Miltner 1937, Dickinson 1953 Keck & Kelly 1965) Venous stasis has also been described as accelerating the healing of fractures (Pearse & Morton 1930) and the periosteal bone formation (Lilly & Kelly 1970)

The discrepancies between the various investigations are probably due to several factors Different sorts of experimental animals have been used and venous stasis has been produced in different ways and at different levels Moreover, the methods used for measuring longitudinal bone growth have been uncertain, probably having serious inherent sources of error which have not been taken into account

[illegible] growth accessi- [illegible] ligation of this vein has been described as having a growth stimulating effect (Borel 1922, Kishikawa 1936, Servelle 1948) The longitudinal bone growth was measured with the tetracycline tech-

nique, making it possible to determine the growth per day with good accuracy (Hansson 1967).

## MATERIAL AND METHODS

*131* white rabbits of both sexes, aged 35–40 days at the time of the operation were used. The rabbits were treated as previously described (Hansson 1967).

During the operation, the animals were given an injection of mebumal sodium intraperitoneally and then anaesthetized with ether. All operations were performed on the left side. In the first group of animals (59 animals, Group I), the femoral vein, the circumflexal veins, and the deep femoral vein were ligated with silk. In the other group of animals (72 animals, Group II), the sciatic vein and the above mentioned veins were ligated.

Of these animals, five in each group were only used to register the venous pressure and for phlebography. The venous pressure was measured about 10 mm distal to the place of ligation in the femoral vein by means of a Scalp Vein Set including a 23 Gauge Needle (Portex®). Phlebograms were made by injection of a contrast medium (Isopaque®) by means of a small polyethylene catheter (P.E. 160) in the femoral and/or the sciatic vein.

The longitudinal bone growth was determined during the day before operation and at different postoperative time intervals up to 40 days after operation in both Groups (see Tables 1 and 2). Each animal received two or four intravenous injections of 1.0 mg oxytetracycline (Terramycin®) per kg body weight with an interval of 24 hours between consecutive injections. The animals were killed about 10 minutes after the last injection by intravenous injection of mebumal sodium.

The rate of longitudinal bone growth was determined in the following regions bilaterally in the proximal tibiae and distal tibio fibulae, and on the right side in the distal radius. These regions were fixed, dehydrated, sectioned manually and examined in a fluorescence microscope as previously described (Hansson 1964, 1967).

## FINDINGS

At the operation, the venous system distal to the ligatures was usually dilated, but no signs of postoperative oedema distal to the ligatures were seen with certainty during the experimental period. Autopsy invariably showed that the surgical wound had healed without complications and that the ligatures were intact.

The phlebograms in the normal unoperated leg showed a venous blood flow not only in the femoral vein and sciatic vein but also in several communicating veins to the vertebral and epigastric veins. In the group of animals with the anterior ligations (Group I), the phlebograms showed that the venous blood rapidly passed through the sciatic vein and the communicating veins in the muscles. In the group of animals with both anterior and posterior ligations (Group II), the liga-

*Table 1 Longitudinal bone growth in μ per day after ligation of femoral vein circumflexal veins and deep femoral vein of the left side (Group I)*

| Observation day | Number of animals | Proximal tibia Right $M \pm s_d$ | Proximal tibia Left $M \pm s_d$ | Proximal tibia Difference between left and right $M \pm s_d$ | Distal tibio fibula Right $M \pm s_d$ | Distal tibio fibula Left $M \pm s_d$ | Distal tibio fibula Difference between left and right $M \pm s_d$ | Distal radius Right $M \pm s_d$ |
|---|---|---|---|---|---|---|---|---|
| Day before operation | 11 | 516 36 | 515 36 | −1 4( ) | 448 31 | 448 30 | 0 6( ) | 405 32 |
| Day after operation | | | | | | | | |
| 1st | 11 | 514 40 | 510 39 | 3 9( ) | 439 39 | 442 36 | 4 11( ) | 459 30 |
| 2nd | 11 | 510 32 | 512 34 | 2 11( ) | 449 34 | 444 32 | −5 6* | 464 29 |
| 4th | 6 | 485 35 | 485 36 | 0 6( ) | 423 37 | 417 39 | −6 27( ) | 430 40 |
| 6th | 6 | 436 42 | 436 41 | 0 7( ) | 361 44 | 364 40 | 3 10( ) | 412 47 |
| 8th | 6 | 496 32 | 493 37 | −3 7( ) | 436 37 | 437 37 | 1 5( ) | 457 41 |
| 10th | 6 | 505 64 | 498 59 | −7 11( ) | 406 74 | 403 72 | −3 5( ) | 448 55 |
| 20th | 6 | 372 [illegible] | 374 38 | [illegible] 8( ) | 283 37 | 279 34 | −5 14( ) | 372 27 |
| 30th | 7 | 356 [illegible] | 355 25 | 0 5(*) | 255 32 | 251 35 | −4 8( ) | 357 28 |
| 40th | 6 | 259 40 | 261 [illegible] | 2 5( ) | 156 29 | 157 31 | 1 2( ) | 273 59 |

Statistical analysis (Student's t test) of the difference

* 0.01<P<0.05 ( ) P>0.05

nique, making it possible to determine the growth per day with good accuracy (Hansson 1967).

## MATERIAL AND METHODS

131 white rabbits of both sexes, aged 35–40 days at the time of the operation were used The rabbits were treated as previously described (Hansson 1967)

During the operation, the animals were given an injection of mebumal sodium intraperitoneally and then anaesthetized with ether All operations were performed on the left side In the first group of animals (59 animals, Group I), the femoral vein the circumflexal veins, and the deep femoral vein were ligated with silk In the other group of animals (72 animals, Group II), the sciatic vein and the above mentioned veins were ligated

Of these animals, five in each group were only used to register the venous pressure and for phlebography The venous pressure was measured about 10 mm distal to the place of ligation in the femoral vein by means of a Scalp Vein Set including a 23 Gauge Needle (Portex®) Phlebograms were made by injection of a contrast medium (Isopaque®) by means of a small polyethylene catheter (PE 160) in the femoral and/or the sciatic vein

The longitudinal bone growth was determined during the day before operation and at different postoperative time intervals up to 40 days after operation in both Groups (see Tables 1 and 2) Each animal received two or four intravenous injections of 1 8 mg oxytetracycline (Terramycin®) per kg body weight with an interval of 24 hours between consecutive injections The animals were killed about 10 minutes after the last injection by intravenous injection of mebumal sodium

The rate of longitudinal bone growth was determined in the following regions bilaterally in the proximal tibiae and distal tibio fibulae, and on the right side in the distal radius These regions were fixed dehydrated sectioned manually, and examined in a fluorescence microscope as previously described (Hansson 1964 1967)

## FINDINGS

At the operation, the venous system distal to the ligatures was usually dilated, but no signs of postoperative oedema distal to the ligatures were seen with certainty during the experimental period Autopsy invariably showed that the surgical wound had healed without complications and that the ligatures were intact

The phlebograms in the normal unoperated leg showed a venous blood flow not only in the femoral vein and sciatic vein but also in several communicating veins to the vertebral and epigastric veins In the group of animals with the anterior ligations (Group I), the phlebograms showed that the venous blood rapidly passed through the sciatic vein and the communicating veins in the muscles In the group of animals with both anterior and posterior ligations (Group II), the liga-

tures did not permit any passage of the contrast medium through these vessels Instead immediately after operation, the contrast medium passed through smaller dilated veins originating from the femoral vein and sciatic vein distal to the ligatures, after a short delay, the sacral veins and the inferior cava vein were filled Two days after operation, a rich collateral circulation was established especially round the ligature of the sciatic vein permitting the venous blood to re-enter this vein Simultaneously all the peripheral parts of the circumflexal veins were filled and took part in a collateral circulation

The preoperative venous pressure in the femoral vein was found to be about 8 5 cm $H_2O$ In the animals with anterior ligation (Group I), the venous pressure immediately after operation increased to about 24 0 cm $H_2O$ One day later, the pressure had decreased to about 9 5 cm $H_2O$ two days after operation the venous pressure was equal to the preoperative pressure In the animals with both anterior and posterior ligation (Group II), the immediate postoperative venous pressure was the same as in the first group of animals but the decrease was slower Thus two days postoperatively, the pressure was found to be about 15 0 cm $H_2O$ after ten days the venous pressure was slightly above the normal—about 11 0 cm $H_2O$ Later, the venous pressure was almost equal to the preoperative pressure

The determination of longitudinal bone growth showed a tendency to general growth retardation immediately after operation This tendency was especially marked in the group of animals with both anterior and posterior ligations and then during the first postoperative day

The comparison of daily longitudinal bone growth between the left operated side and the right control side revealed no significant differences in growth rate (Tables 1 and 2) However, small and variable differences of low significance were registered in both groups of animals but no general tendency was found

## DISCUSSION

The general retardation of longitudinal bone growth observed during the first postoperative days was probably due to general impairment of the blood flow after the operation This growth retardation was marked in the second group of animals where the operation was more extensive than in the first group of animals Similar growth retardation has previously been observed after bone operations (Hansson 1967), which are known to reduce the blood flow (Gelin 1956 Bergentz 1961)

*Table 2 Longitudinal bone growth in μ per day after ligation of femoral vein circumflexal veins deep femoral vein and sciatic vein of the left side (Group II)*

| Observation day | Number of animals | Proximal tibia Right $M \pm s_d$ | | Proximal tibia Left $M \pm s_d$ | | Proximal tibia Difference between left and right $M \pm s_d$ | | Distal tibio fibula Right $M \pm s_d$ | | Distal tibio fibula Left $M \pm s_d$ | | Distal tibio fibula Difference between left and right $M \pm s_d$ | | Distal radius Right $M \pm s_d$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Day before operation | 12 | 420 | 64 | 418 | 67 | 1 | 11( ) | 356 | 67 | 351 | 68 | −6 | 13( ) | 372 | 60 |
| Day after operation | | | | | | | | | | | | | | | |
| 1st | | 375 | 58 | 382 | 56 | 7 | 11( ) | 314 | 60 | 318 | 61 | 4 | 17( ) | 330 | 69 |
| 2nd | | 400 | 41 | 406 | 48 | 6 | 11( ) | 339 | 41 | 344 | 47 | 5 | 18( ) | 360 | 37 |
| 4th | 12 | 372 | 45 | 389 | 46 | 17 | 21* | 329 | 40 | 335 | 47 | 5 | 11( ) | 348 | 49 |
| 6th | 8 | 400 | 33 | 403 | 34 | 4 | 9( ) | 325 | 33 | 330 | 35 | 5 | 12( ) | 360 | 45 |
| 8th | 7 | 423 | 31 | 434 | 24 | 11 | 25( ) | 351 | 36 | 346 | 35 | −5 | 5* | 388 | 43 |
| 10th | 9 | 376 | 32 | 374 | 35 | −1 | 9( ) | 320 | 30 | 321 | 32 | 1 | 10( ) | 353 | 35 |
| 20th | 7 | 421 | 33 | 421 | 30 | 0 | 0( ) | 333 | 30 | 332 | 23 | −1 | 15( ) | 387 | 37 |
| 30th | [illegible] | 391 | 31 | 402 | 31 | 11 | 13( ) | 319 | 33 | 313 | 29 | −6 | 7( ) | 372 | 27 |
| 40th | 6 | 346 | 34 | 336 | 35 | −10 | 11( ) | 227 | 26 | 226 | 25 | −2 | 6( ) | 339 | 32 |

Statistical analysis (Student's t test) of the difference
* $0.01 < P < 0.05$ ( ) $P > 0.05$

flexal veins, and the deep femoral vein resulted in a temporary venous stasis. Additional ligation of the sciatic vein resulted in the same degree of venous stasis but a more longstanding effect. Neither of the operations resulted in growth stimulation or growth retardation compared with the control side. On the contrary, the ligation resulted in a minor temporary general growth retardation during the first days after the operation.

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The operative procedure used in this investigation unquestionably results in venous stasis as the venous pressure increased temporarily and there was a delay of the venous blood flow according to the phlebograms. This venous stasis was of the same degree both after anterior ligation of veins and the additional ligation of the sciatic vein, but it was more longstanding in the latter case. As found in a previous investigation (Brookes & Singh 1972), an extensive venous collateral circulation develops after venous ligation, bypassing the obstruction and eliminating the venous stasis.

The present investigation showed no obvious growth stimulating effect after ligation of veins. The differences of low significance found in this investigation were of the same order or slightly above the error of method for determination of the growth rate (Hansson 1967). Moreover, these small differences were variable in time and localization and seem uncertain. The result thus agreed well with the results obtained by some previous investigators (Wu & Miltner 1937, Dickinson 1953, Keck & Kelly 1965). Furthermore, it has previously been found that ligation of veins does not result in active but passive hyperaemia with a slight reduction of the intraosseous blood flow and a varying intramedullary pressure (Keck & Kelly 1965, Sunden 1967).

There are probably several reasons why many investigators (Borel 1922, Bergmann 1931, Kishikawa 1936, Servelle 1948, Hutchison & Burdeaux 1954, Colt & Iger 1963) have found venous stasis to be growth stimulating. In general, the series of animals used in most investigations were small. The most probable explanation for the differing results is the large error of the previously used methods for measuring the rate of longitudinal bone growth. Moreover, the application of a tourniquet to achieve venous stasis probably results in a compression not only of superficial and deep veins but also of other structures. Also, the growth stimulation might not be a result of the venous stasis, but of the general operative trauma to the extremity. Trauma is known to induce active hyperaemia and thereby stimulation of longitudinal bone growth (Hansson 1967).

## SUMMARY

The effect of ligation of veins on the longitudinal bone growth was studied in growing white rabbits. The daily longitudinal bone growth was determined with the tetracycline technique from the day before up to 40 days after operation. Ligation of the femoral vein, the circum-

Acta orthop scand 46 185–189 1975

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# NUCLEIC ACIDS IN ARTICULAR CARTILAGE FROM RABBITS OF DIFFERENT AGES

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Accepted 16 xi 74

The joint cartilage varies considerably with age (Rosenthal et al 1941 Barnett et al 1963 Mankin 1963 Mankin & Baron 1965 Davies 1969 and Mankin 1970) Histologically cartilage is a special type of tissue and has one of the lowest ratios of cell mass to matrix (Hamerman & Schubert 1962) The chondrocytes are sparse even in very young cartilage A decrease in the number of chondrocytes with advancing age in the cartilage of rabbits has been found in some investigations (Barnett et al 1963 Mankin & Baron 1965) Mankin (1968) counted the chondrocytes in cartilage from rabbits of various ages and found that in immature animals (2 months) the counts are in the range of $2\,55 \times 10^5$ cells/mm$^3$ at 6 months $2\,26 \times 10^5$ and in fullgrown animals (18 months) $1\,92 \times 10^5$ cells/mm$^3$ Meachim & Collins (1962) found no such decrease in man However Stockwell (1967) found that the cell density in articular cartilage diminished during maturation (0–30 years) by about sevenfold but during ageing (31–89 years) there was no significant change in the cell density of the whole thickness of articular cartilage

This paper concerns quantitative determination of nucleic acids in the articular cartilage from rabbits of varying age and the new formation of DNA

## MATERIAL AND METHODS

The material consisted of three groups of animals (grey silver) five immature animals (6 weeks old) weighing 470 to 640 g (mean 535 g) six fullgrown animals (1 1/4 years old) weighing 2 110 to 2 530 g (mean 2,260 g) and five old rabbits

Supported by Herman Järnhardts stiftelse, Lilla och Gustaf af Ugglas fond and Svenska Läkaresällskapets fonder

Wu Y K & Miltner L J (1937) A procedure for stimulation of longitudinal growth of bone An experimental study *J Bone Jt Surg* 19 909 921

*Key words* bone growth phlebography rabbits tetracycline veins

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*Table 1 Concentration of nucleic acids and synthesis of DNA in articular cartilage from immature, fullgrown and old rabbits*

| Cartilage | γ DNA/mg | γ RNA/mg | γ RNA/ γ DNA | cpm DNA/mg | cpm DNA/γ DNA |
|---|---|---|---|---|---|
| Immature rabbits | 1.41±0.53 | 14.18±4.32 | 10.51±2.51 | 72.94±62.99 | 46.83±28.85 |
| Fullgrown rabbits | 0.86±0.28 | 8.94±2.08 | 10.85±2.17 | 7.25± 2.34 | 9.19± 4.20 |
| Old rabbits | 0.83±0.37 | 7.88±1.03 | 10.60±3.31 | 3.41± 1.27 | 4.87± 2.92 |
| obability level 1 2 | 01>$P$>001 | 01>$P$>001 | — | 01>$P$>001 | $P$>001 |
| obability level 1 3 | 05>$P$>01 | $P$>001 | — | 01>$P$>001 | $P$>001 |
| obability level 2-3 | — | 2>$P$>1 | — | $P$>001 | 05>$P$>01 |

## DISCUSSION

Immature cartilage grows by mitotic division of the chondrocytes. In the immature cartilage, cell division occurs in two zones: one just below the articular surface, probably the growth zone of the joint cartilage and the other zone in the basal parts of the cartilage, probably constituting the growth zone of the epiphyseal nucleus. When the rabbit approaches maturity the outer zone disappears and later also the proliferation zone adjacent to the epiphyseal nucleus. When a well-defined zone with calcified cartilage has formed the chondrocytes cease to divide. Mitosis has never been demonstrated in normal joint cartilage in adult human beings or animals (Elliott 1936, Clark & Clark 1942, Crelin 1957, Crelin & Southwick 1960, Mankin 1963 a, 1963 b, 1964, 1968, Hulth et al 1972, Telhag 1972, 1973). The present investigation showed that the amounts of DNA and RNA decreased when the animals reached adult age, but that no further change occurred in the nucleic acids with subsequent increase in age. There is a constant ratio between the concentration of DNA and the number of cells in the tissue. The results agree with those reported by earlier investigators (Rosenthal et al 1941, Barnett et al 1963, Mankin 1963 a, Mankin & Baron 1965, Mankin 1968, Davies 1969 and Mankin 1970) regarding the amounts of DNA while the RNA concentration, as far as we know, has never before been studied as regards variation with age.

The chondrocytes of articular cartilage appear to "turn off" the switch for DNA synthesis at maturity rather than "breaking" the switch (Mankin 1970). The same author (Mankin 1968) pointed out in another investigation that considerable changes occur in the articular

(more than 4 years old), weighing between 3 280 and 5 150 g (mean 3 840 g) Forty $\mu$Ci $^3$H thymidine* was injected into both knees of all animals Four hours later the animals were killed by an overdose of nembutal Immediately after the animals had died the cartilage from the articular surfaces of the tibia and the femur were dissected with a knife, care being taken to avoid inclusion of subchondral bone and other tissue The cartilage of each knee was treated separately The material was weighed (wet weight)

The excised cartilage was placed in a mortar and covered with liquid nitrogen and pulverized It was then homogenized in 5 ml of 10 per cent TCA (trichloroacetic acid), and the acid soluble nucleotides were separated by centrifugation and washed twice, each time with 5 ml of the same solvent The insoluble residue was treated with 10 ml of 0 3 M potassium hydroxide for 18 hours at 37° C to hydrolyze RNA which thereby was brought into solution The solution was adjusted to pH 7 by addition of 70 per cent perchloric acid An equal volume of 5 per cent TCA was added to the neutral solution This resulted in precipitation of protein and DNA which were separated from the solution by centrifugation and washing of the precipitate twice each time with 5 ml of 5 per cent TCA

*RNA and DNA in the separated fractions* were determined with the orcinol reaction (Mejbaum 1939) and the Ceriotti procedure (Ceriotti 1952), respectively The separation of RNA and DNA was checked in all experiments by applying both reactions to the RNA as well as the DNA fraction

Each sample was assayed for radioactivity ($^3$H thymidine) after suspension in 10 ml of Instagel (Packard), using a two channel Packard Tri Carb liquid scintillation spectrometer The results were recorded as counts per milligram of wet weight per minute

## RESULTS

The results are summarized in Table 1 The concentration of DNA and RNA relative to the amount of tissue was significantly lower in cartilage from fullgrown and old rabbits when compared with that in young rabbits

*The synthesis of DNA was significantly less in joint* cartilage from fullgrown and old animals than in cartilage from young animals, both in relation to the amount of tissue and to the amount of DNA

The concentrations of DNA and of RNA were the same in fullgrown rabbits as in the old animals The synthesis of DNA relative to the amount of tissue and the amount of DNA was less in the old animals than in the fullgrown ones

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* From the Radiochemical Center Amersham Aqueous solution containing 5 000 mCi/mM

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*Key words* cartilage nucleic acid autoradiography rabbit

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surfaces in the period of maturation, but that little variation is noted with senescence The present investigation showed, firstly, that once the animal reaches maturity the synthesis of DNA decreases markedly and, secondly, that the DNA synthesis decreases further with the advancing age of the animal This might suggest that the ability of the cartilage to proliferate decreases with age

## SUMMARY

The joint cartilage of immature, adult and old rabbits was examined The joint cartilage in adult and old rabbits contained less nucleic acids than that in young rabbits The synthesis of DNA decreases with advancing age, while no difference was found in the concentration of nucleic acids between adult and old rabbits

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*Table 1 Characteristics of the patient material*

| | Age (years) | Duration of coma m – months | Duration of the bedridden condition | Date of diagnosis of ossification after onset of coma | Neurological deficiency after coma R – right L – left | Localization of ossification | Anatomical paralysis | Functional paralysis | No paralysis |
|---|---|---|---|---|---|---|---|---|---|
| 1 | [illegible] | 2 m | 3 m | 2 m<br>2.5 m | hemiplegia R | Elbow R<br>Hip I | + | | +<br>+ |
| 2 | 26 | 1 m | 6 m | 3.5 m | nil | Elbow L | | | |
| 3 | 27 | 1.5 m | 5 m | 2.5 m<br>4.5 m | hemiplegia I | Elbow L<br>Hip I | +<br>+ | | |
| 4 | 29 | 7 m | 10 m | 9 m | hemiplegia L | Elbow I | + | | |
| 5 | 31 | > 8 m | > 8 m | 3 m<br>4 m | hemiplegia R<br>functional hemiplegia L | Shoulder R<br>Elbow L | + | + | |
| 6 | 40 | 0.5 m | 7 m | 5 m | hemiplegia R | Elbow R | + | | |
| 7 | 23 | > 6.5 m | > 6.5 m | 4.5 m | tetraplegia | Elbow L | + | | |
| 8 | 25 | 4.5 m | 5 m | 3.5 m | hemiplegia R<br>functional paralysis of the leg | Hip R | + | | |
| 9 | 41 | > 4 m | > 8 m | 1 m<br>5 m | tetraplegia | Elbow R<br>Elbow L | +<br>+ | | |
| 10 | [illegible] | 3.5 m | 4 m | 3 m<br>1.5 m | hemiplegia R | Elbow R<br>Elbow I | + | | + |
| 11 | 58 | > 4 m | > 4 m | 2 m | tetraplegia | Elbow R<br>Elbow L | +<br>+ | | |
| 12 | 20 | > 4 y | > 3 y | 7 m | tetraplegia | Elbow R<br>Elbow L | +<br>+ | | |
| 13 | 26 | 2 m | 3.5 m | 6 m | functional tetraplegia without paralysis | Hip R | | + | |

Acta orthop scand 46, 190–198, 1975

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# CLINICAL SURVEY OF AND PATHOGENIC APPROACH TO PARA-ARTICULAR OSSIFICATIONS IN LONG-TERM COMA

HERMAN MIELANTS, ERIC VANHOVE, JACQUES DE NEELS & ERIC VEYS

Accepted 23 xii 74

**Para-articular ossifications were recognized as a clinical entity in 1918 by Dejerine & Ceillier We have surveyed a large group of patients with para-articular ossifications complicating long-term coma The pathogenic factors of the disease are discussed**

## MATERIAL

Twenty six patients in long term coma following cerebral traumatic lesions were surveyed (Table 1) A minimal limitation of passive joint mobility was sufficient for a decision to be made to investigate a joint roentgenologically Para articular ossification was found in seven out of 26 patients Six other patients were added to this series, as they presented para articular ossifications complicating long term coma of a non traumatic origin For technical reasons frequency of ossification in this group could not be determined accurately

The age of the 13 patients (8 males and 5 females) ranged from 18 to 58 years All of them presented intracranial lesions of various origins (seven traumatic three vascular one tumour one infectious and one occurring after intoxication with amitryptiline)

The duration of coma ranged from 15 days to more than 3 years In all cases at least functional tetraplegia was observed during the coma i e the patients were unable to perform conscious intentional muscle contractions but involuntary responses to nerve stimulation or pain reflexes were possible Consideration of functional plegia of a limb implies no (anatomical) interruption of the efferent nerve tracts All patients were confined to bed for a long period of time and remained completely bedridden for from 3 months to more than 3 years

Some patients, on recovering consciousness, had an anatomical tetraplegia or hemiplegia Others presented a functional plegia Para articular ossification occurred at the earliest 1 month and at the latest 8 months after the onset of coma All patients were still completely bedridden when ossification appeared Seven patients were still comatose, but six others had already woken up from the coma

*Table 1 Characteristics of the patient material*

| | Age (years) | Duration of coma m months | Duration of the bedridden condition | Date of diagnosis of ossification after onset of coma | Neurological deficiency after coma R right L=left | Localization of ossification | Anatomical paralysis | Functional paralysis | No paralysis |
|---|---|---|---|---|---|---|---|---|---|
| 1 | [illegible] | 2 m | 3 m | 2 m | hemiplegia R | Elbow R | + | | + |
| | | | | 2.5 m | | Hip L | | | + |
| 2 | 26 | 1 m | 6 m | 3.5 m | nil | Elbow L | | | |
| 3 | 27 | 1.5 m | 5 m | 2.5 m | hemiplegia L | Elbow L | + | | |
| | | | | 4.5 m | | Hip L | + | | |
| 4 | 29 | 7 m | 10 m | 9 m | hemiplegia L | Elbow L | + | | |
| 5 | 31 | > 8 m | > 8 m | 3 m | hemiplegia R | Shoulder R | + | | |
| | | | | 4 m | functional hemiplegia L | Elbow L | | + | |
| 6 | 40 | 0.5 m | 7 m | 5 m | hemiplegia R | Elbow R | + | | |
| 7 | 23 | > 6.5 m | > 6.5 m | 4.5 m | tetraplegia | Elbow L | + | | |
| 8 | 25 | 2.5 m | 5 m | 3.5 m | hemiplegia R functional paralysis of the leg | Hip R | + | | |
| 9 | 41 | > 8 m | > 8 m | 1 m | tetraplegia | Elbow R | + | | |
| | | | | 5 m | | Elbow L | + | | |
| 10 | 50 | 3.5 m | 4 m | 3 m | hemiplegia R | Elbow R | + | | |
| | | | | 1.5 m | | Elbow L | | | + |
| 11 | 58 | > 4 m | > 4 m | [illegible] m | tetraplegia | Elbow R | + | | |
| | | | | | | Elbow L | + | | |
| 12 | 20 | > 3 y | > 3 y | 7 m | tetraplegia | Elbow R | + | | |
| | | | | | | Elbow L | + | | |
| 13 | 26 | 2 m | 3.5 m | 6 m | functional tetraplegia without paralysis | Hip R | | + | |

*Figure 1. Roentgenograms of the right elbow of Case 1. Early stage with posterior localization of the ossification.*

*Figure 2. Roentgenogram of the right elbow of Case 1 one month later than in Figure 1. The ossification is more homogeneous but no enlargement of the lesion is observed.*

In the 13 patients, para-articular ossification was found encircling 20 joints. A high frequency of elbow involvement (15 of the 20 joints) must be emphasized; furthermore one shoulder and four hips were implicated. In the elbow region (Figures 1 and 2) roentgenograms revealed ossification on the posteromedial aspect of the distal end of the humerus. The para-articular ossification resembled a triangle with the base localized at the olecranon and the apex in the mass of the triceps muscle (Figure 1). Later an anterior ossification in the proximal part of the forearm was seen (Figure 2). In all cases of elbow involvement, posterior ossifications were present.

Around the shoulder, the demarcation of the anterior localization at the proximal humeral epiphysis was not clearly defined. Ossifications localized in the hip extended from the anteromedial border of the femoral neck to the pelvis in the adductor region (Figure 3) or from the posterolateral border of the greater trochanter proximally in the gluteal region (Figure 4).

In all but one case, roentgenological lesions were already present at the moment of clinical diagnosis. Roentgenological evolution was carefully followed and can be summarized in a few words: in the early stages, ossification is diffuse, irregular and not very homogeneous but the final delimitation is immediately marked. Later the ossification becomes more homogeneous but no increase in the

*Figure 3 Right hip of Case 13, ossification from the anteromedial border of the femoral neck to the pelvis in the adductor region*

*Figure 4 Left hip of Case 3, posterolateral ossification from the greater trochanter to the gluteal region*

size of the original area involved occurs (*Figures 1 and 2*) It is very important to note that in five cases, ossification occurred in a limb which was not anatomically paralysed, although functional plegia of the involved limbs was present in the earliest stage of coma

## DISCUSSION

In this study para-articular ossification emerges as a frequent complication of long-term coma in adults The reported frequency (7/26) is higher than that described in children (6/112) by Hoffer et al. (1971) Para-articular ossification is probably often overlooked in patients who cannot easily be examined clinically, as is certainly the case in coma

The pathogenesis of [illegible] very inconsistent hypo [illegible] occurrence of metaplas [illegible] intermuscular and perimuscular con-

nective tissue The origin of the metaplasia is unknown Two groups of causative factors are proposed in the literature neurological components (Dejerine et al 1919) and local factors, mostly related to the neurological factors (Benassy et al 1960)

We think that *all aetiologic forms of the affection* have two factors in common: 1) a prolonged completely bedridden condition and 2) a paralytic or functional immobility of several limbs The immobility is considered to be paralytic when an anatomical defect of the efferent nerve tracts from the cerebral cortex exists Extensive paralysis will lead to complete *immobility and a completely* bedridden condition When the efferent tracts from the cerebral cortex to the muscle fibres are unaffected, agents which disturb the normal dynamic and static muscle contraction can lead to functional immobility and a completely bedridden condition Among these agents pain, which occurs during muscle contraction in extensive burn lesions, must be an important factor. We would also like to mention defects in the afferent tracts to the cerebral cortex, as are found in coma and in cerebral lesions preventing the stimulus to voluntary contraction from reaching the cortical motor centre Functional or paralytic immobility and a completely bedridden state possibly involve local circulatory and metabolic disorders inducing metaplasia

Approaching the different diseases in which para-articular ossifications are observed, we in fact found arguments for this theory Para articular ossification is most frequently encountered in para and tetraplegia subsequent to cord lesions In these cases ossification is only present in paralytic regions (in paraplegia only the knees or the hips are involved, in tetraplegia ossifications can also occur at the elbow and shoulder level) Paralytic immobility is certainly present in these cases Liberson (1953) reports that para-articular ossification occurs more frequently in cervical than in lumbar lesions We have *noticed that immobility and the bedridden condition are more* complete in cervical lesions Stehman (1959) reported ossifications complicating six cases out of 25 with multiple sclerosis All six patients were at an advanced stage of the disease with a complete quadriplegia and were absolutely immobile and bedridden In addition, para-articular ossification is described complicating hemiplegia following cerebral vascular lesions The frequency of ossifications is lower in these cases and varies between 0 8 and 3 per cent (Schott et al 1959, Stehman 1959) These patients are in fact mobilized earlier, the mobility of the healthy limbs is maintained and the period of complete immobility and the

bedridden state is much shorter It is important to note that various authors (Benassy 1957, Stehman 1959, Renier & Cheguillaume 1966) reported ossification on the non-paralytic side of patients with hemiplegia, who were kept in bed for a long period of time for other reasons

Para articular ossification is never described in peripheral nerve lesions, but these patients are never kept in bed nor are they strictly immobilized for a long period of time In poliomyelitis, however, para-articular ossification has been described with a frequency of 0 3 per cent (Stoikovic et al 1955) In the 14 cases found in the literature (Costello & Brown 1951, Freiberg 1952, Hansson & Austlid 1955, Stoikovic et al 1955) complete tetraplegia was present (except for one case with a paraplegia up to the navel) The low frequency of ossification in this affection can be explained by the fact that very few patients with poliomyelitis reach a sufficiently advanced stage of the disease and survive Thus it seems that ossification is not merely induced by a lesion of the nerve system, but that complete immobilization is also required

Fifteen cases of para articular ossification complicating tetanus are reported in the literature (Gunn & Young 1959, Warter et al 1965, Renier et al 1966) Ossifications occur in the early stage of this affection (sometimes after 2 or 3 days) and the roentgenological lesions are often different from those observed in other diseases The possibility exists that in tetanus, the roentgenological lesions should be considered as ossification of intramuscular bleedings rather than as para articular ossifications The two patients, described by Renier et al (1966) showing the classic picture of para articular ossification, were both curarized followed by complete paralysis and immobilization

In burns ossification only occurs in patients kept in bed for a long period of time with very extensive lesions (more than 22 per cent) (Evans 1966) Here also functional immobility is a very important factor

We found 27 cases of para articular ossifications complicating long-term coma in the literature (Garcin et al 1959, Schott et al 1959, Stehman 1959 Wharton & Morgan 1970, Hoffer et al 1971) We have assembled 13 cases of para articular ossification complicating long-term coma Long term coma can finally result in tetraplegia, but as already described in the literature (Benassy 1957) we also found ossifications in patients with no remaining paralysis Here too, functional immobilization is probably an important inducing factor In our

patients coma continued for at least 2 weeks, during this period a paralytic or at least a functional immobility was present Although all patients were regularly mobilized passively, ossifications occurred nevertheless In most patients who woke from the coma, para articular ossification occurred after the recovery of consciousness, but it must be remembered that all patients were kept in bed for a further period and that ossification occurred before they became ambulant again It is clear that a prolonged bedridden state, for at least 3 months, is very important in this study In four patients residual paralytic tetraplegia was found after coma (cases 7, 9, 11, 12), one patient had a functional tetraplegia (case 13), seven patients presented residual paralytic hemiplegia (cases 1, 3, 4, 5, 6, 8, 10), in one of the seven, functional plegia was found on the other side (case 5) and in one patient no residual plegia was observed (case 2) We thus surveyed six patients with paralytic or functional tetraplegia and six patients with hemiplegia Contrary to reports found in the literature, where frequency of para-articular ossification is observed to be higher than 20 per cent in tetraplegia and lower than 1 per cent in hemiplegia, we found as many patients with residual hemiplegia as patients with residual tetraplegia having para-articular ossifications

We think that neither the nature of the nerve lesions, nor the type of paralysis is important in the induction of ossification, but the role of coma, of long immobility and the bedridden condition must be stressed Neurological sympathetic, trophic and sensitive factors may be less important, motor (anatomical or functional) factors, on the other hand, are essential for the occurrence of ossification Another pertinent finding must be mentioned Although para-articular ossifications occur mostly in paralytic regions, we found ossifications in five patients (cases 1, 2, 5, 10, 13) in limbs which were not paralytic and in which the integrity of the efferent nerve tract could be demonstrated In three of the five cases no functional plegia was observed after the period of coma (cases 1, 2, 13)

Even if the aetiopathogenesis of para articular ossification still remains unknown, we can conclude that besides an individual promoting factor, a prolonged complete immobilization seems to be an inducing agent A bedridden state alone is not sufficient since ossification does not occur in all the diseases associated with continued bed-rest, but a functional or anatomical immobility seems to be an aggressive agent The immobility can induce secondary vasomotor, metabolic and trophic disorders, which can give rise to metaplasia

SUMMARY

1 Thirteen patients with para articular ossification complicating long term coma are presented In a series of 26 patients with long term coma following cerebral traumatic lesions, seven cases were found with para articular ossification

2 The high frequency of elbow involvement is emphasized and in all these cases posterior ossifications were present

3 In five patients, ossifications were observed in limbs which were not paralytic and in which integrity of the efferent nerve tracts could be demonstrated

4 The importance of functional or paralytical immobility and of a completely bedridden condition in the patients is emphasized

5 The aetiopathogenesis of para articular ossifications still remains unknown but a prolonged complete immobilization possibly induces vasomotor metabolic and trophic disorders, which can give rise to metaplasia

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Acta orthop. scand. 46, 199-204, 1975

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# DYNAMIC REPAIR OF ACROMIO-CLAVICULAR DISLOCATION

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Accepted 21.x.74

The acromio-clavicular (A.C.) joint suffers injury very frequently, especially amongst those involved in physical activity and those who are injured on the roads. This joint is of small dimensions and is very unstable; stability is maintained by the adjacent ligaments.

Our purpose is to present a physiological approach to the dynamic repair of the A.C. joint dislocation.

## CLINICAL MATERIAL

Twenty patients with an A.C. dislocation were treated in our department during the years 1967-1973.

*Sex incidence*: 18 out of 20 patients were male.

*Age distribution*: This lesion generally occurred in young people, the majority occurring at between 18 and 25 years of age, the youngest patient being 17 and the oldest 60 years of age.

*Side of dislocation*: There was no significant difference. We had 12 left-sided injuries and 8 on the right; one patient had a bilateral dislocation.

*Circumstance of injury*: The great majority of these lesions occurred in young people as they are most exposed to trauma. Thus 13 were injured in road accidents and 7 during sporting activities.

*Time of operation*: 16 (80 per cent) of the cases were treated surgically within the first 2 weeks of injury. Four cases (20 per cent) presented for treatment at times ranging from 6-36 months after the initial trauma complaining of persistent shoulder pain and disability. These too were operated upon.

## TREATMENT

The procedure of transposition of coracoid to clavicle was first described by Dewar & Barrington (1965) who presented only five cases.

A number of modifications to the original technique, which we believe to be of importance in achieving a good result, were instituted.

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*Key words* : para articular ossification, long term coma, paraplegia, tetraplegia hemiplegia

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Evaluation of results was performed according to

(a) Residual pain
(b) Shoulder motion
(c) Deformity
(d) X ray check

(a) *Residual pain* Four of the twenty patients complained of moderate pain during strong physical activity in the region of the clavicle to which the coracoid process was fixed The screw was removed in these patients and the pain disappeared In one of the patients the residual pain was severe and he developed a post traumatic arthrosis of the joint Notwithstanding the operation the dislocation of the A C joint remained and an excision of the distal portion of the clavicle was performed freeing him of the pain

(b) *Shoulder motion* Motion of the shoulder was evaluated according to abduction and elevation of the arm with free motion of the scapula In one patient there was slight restriction of abduction the poor result being due to a post traumatic arthrosis After resection of the distal end of the clavicle shoulder mobility returned almost to normal

(c) *Deformity* The above-mentioned patient had a prominence of the distal end of the clavicle and a second patient also presented with a slight prominence because of subluxation of the A C joint

(d) *X ray* The X rays revealed maintenance of the reduction in 18 out of 20 cases One had a recurrent dislocation and another joint subluxation but the latter was symptomless The X ray diagnosis was made with the patient in a standing position with a 2 kg weight held in each hand

According to this evaluation 18 (90 per cent) gave excellent results One was fair (5 per cent) with subluxation of the A C joint but without pains or restriction of mobility One poor result (5 per cent) presenting with pains and restricted mobility ended in subsequent resection of the distal end of the clavicle

## DISCUSSION

The multiplicity of operations and techniques in the treatment of A C dislocation indicates the difficulties involved in perfecting a method of management in these injuries

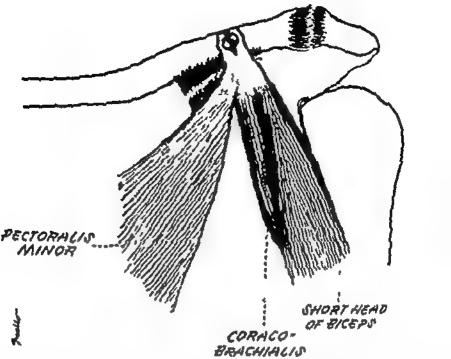


*Figure 1 Technique of transfer of the tip of the coracoid process with the insertion of short head of biceps, coraco brachialis and a third of pectoralis minor muscles to the clavicle and repair of the A-C joint*

Surgical exposure through the deltopectoral groove was performed with the patient in the semi sitting position The deltoid was detached from the clavicle to expose the A C joint The terminal third of the coracoid process was resected together with the origin of the short head of biceps the coraco brachialis and a third of pectoralis minor and a screw inserted through the resected coracoid process which was transferred to the superior surface of the clavicle just above the coracoid process This differs from the technique of Dewar & Barrington in that they insert the screw from below In this way the active action of biceps and coraco brachialis will bring down the clavicle and maintain it in its normal position

At times we have found the torn capsule and ligaments of the A C joint to be interposed between the acromion and the clavicle thus interfering with the reduction (Figure 1)

In our series we exposed the A C joint to make certain that the reduction was completed and where possible we repaired the joint capsule and the ligaments of the A-C joint This step is an important modification of the original technique Immobilization was with a Velpeau dressing for 4 weeks

## RESULTS

Twenty patients were reviewed between 1967 and 1973 with a minimal follow-up time of 1 year and a maximal of 6 years, the average being 3 years

The lesions which influence the results and thus require correction are

(a) damage to the meniscus of the A C joint (injury requires excision)
(b) inverted intra articular ligaments which need to be repaired
(c) muscle tears require suturing

Strict attention to these factors prevents post traumatic arthrosis of the A C joint, thus giving a mobile and pain free joint

In the A C techniques there is the disadvantage that the fixation can be lost by breakdown of the suture or possible migration of the wires or the ligamentous repair fails because of stretch and elongation with subluxation or recurrent dislocation occurring

The coraco-clavicular techniques have the big disadvantage that they do not act over the region of the pathology and this results in degenerative changes

Screw fixation gives rigid fixation which is unphysiological and limits the rotatory movement of the clavicle Shoulder abduction then needs to be compensated by scapula movement

The mixed technique using fascia and other ligaments has the same disadvantage of loss in strength by stretching This is why we advocate a physiological approach to the repair of these traumatic lesions by fixing the clavicle dynamically, viz coraco-biceps muscle transfer

Resection of the distal end of the clavicle relieves the pain but does not prevent the change of position of the shoulder joint, with anterior dropping of the shoulder resulting in fatigue

SUMMARY

Twenty patients with complete acromio-clavicular dislocation treated between 1967 and 1973 were reviewed with a follow up time of from 1 8 years the average being 3 years

They were treated by transposition of coraco-brachialis short head of biceps and a third of pectoralis minor from their origin in the coracoid process to the clavicle together with repair of the acromio-clavicular joint

The results were evaluated according to pain, motion deformity and X rays with 90 per cent excellent results 5 per cent fair and 5 per cent poor

Discussion of the other types of treatment is presented

Disagreement exists as to whether conservative or operative treatment is preferable (Allman 1967)

Conservative management consists of

(a) Adhesive dressing (Watson-Jones 1955),
(b) Braces, and
(c) Hanging-type cast

Urist (1963) favours the conservative methods

Lazcano et al (1961) concluded that greater consideration should be given to closed methods in fresh injuries because of disappointment with their results following open reduction and fixation They suggest that if *disability remains, surgical treatment should be performed at a* later date On the other hand Jacobs & Wade (1966) advocate open reduction and internal fixation of the A-C joint in an acute and complete dislocation

There are numerous methods of operative treatment Basically they can be divided into four categories

I *A-C techniques*
  (a) Suture of the joint
  (b) Transfixation by wires, screws or pins
  (c) Ligament plasty with fascia or ligaments

II *Coraco-Clavicular techniques*
  (a) Metallic fixation by screwing (Bosworth 1941) or cerclage
  (b) Plastic fixation by fascia or ligaments
  (c) Muscle transfer of coracobiceps (Dewar & Barrington 1965)

III *Mixed techniques*
  (a) Fixation of the A-C joint and suture of coraco-clavicular ligaments (Crenshaw 1963)
  (b) Fixation of the A-C joint and plasty of coraco clavicular ligaments (Dupont et al 1971)
  (c) Dynamic repair with transference of coraco brachialis, short head of biceps and one third of pectoralis *minor* together with repair of the A-C joint

IV *Arthroplasty with excision of distal end of clavicle*

Each of the above-mentioned methods has its advantages which are highlighted by the various authors and the number of good and poor results are due not to the type of treatment or technique but to whether the pathology has been treated or not

Acta orthop scand 46 205–210 1975

Martina Hansens Hospital Sandvika, Norway

# CALCIFIC TENDINITIS IN THE SHOULDER REGION

## *A Review of 43 Operated Shoulders*

ASLE VYBOSTAD

Accepted 20 xi 74

Painful shoulder is a very common disorder Tendinitis of the supraspinatus tendon is the most common lesion encountered The reason for this is sometimes clearly demonstrated at operation, in the middle range of abduction the supraspinatus tendon impinges on the tip of the acromion Furthermore some patients experience pain only in the degree of abduction mentioned It is generally agreed that most patients respond well to conservative treatment and the prognosis is good Surgical treatment is reserved for those few patients in whom prolonged conservative treatment has failed The purpose of this review is to state the results of operative treatment as carried out in this hospital

### MATERIAL AND METHODS

A total of 43 shoulders in 39 patients were operated upon for calcific tendinitis at Martina Hansens Hospital during the period 1960–1973 Only one shoulder without a traceable calcific deposit was operated upon and it is included here Sufficient information has been obtained from 38 patients (*43 shoulders*) 8 shoulders have been examined personally and 35 by return of a questionnaire The patients were asked to evaluate the results as excellent good or poor They were asked to recall the length of time which elapsed before they were free from pain and had regained normal movement of the shoulder

Three types of operations have been employed simple excision of the calcific deposit (Group A) excision of deposit combined with partial resection of the acromion (Group B) and partial resection of the acromion alone (Group C) In Group C the calcific deposit could not be easily identified and was therefore left *in situ* The bone piece resected has usually been about 1½ × 3 cm The plane of the resection has been made oblique with the purpose of preventing it from reaching too far posteriorly which here is *considered to* be a beginner's pitfall There were no typical differences in the indications for simple excision of the deposit or resection of the acromion All the patients had a long history of pain and conservative treatment had failed to relieve their symptoms The diagnosis was confirmed by a dense shadow in the region of the supraspinatus tendon on x ray examination All pa

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*Key words:* acromio-clavicular, dislocation.

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A total of 45 shoulders in 39 patients were operated upon for calcific tendinitis at Martina Hansens Hospital during the period 1960–1973 Only one shoulder without a traceable calcific deposit was operated upon and it is included here Sufficient information has been obtained from 38 patients (43 shoulders) 8 shoulders have been examined personally and 35 by return of a questionnaire The patients were asked to evaluate the results as excellent good or poor They were asked to recall the length of time which elapsed before they were free from pain and had regained normal movement of the shoulder

Three types of operations have been employed simple excision of the calcific deposit (Group A) excision of deposit combined with partial resection of the acromion (Group B) and partial resection of the acromion alone (Group C) In Group C the calcific deposit could not be easily identified and was therefore left in situ The bone piece resected has usually been about 1½ × 3 cm The plane of the resection has been made oblique with the purpose of preventing it from reaching too far posteriorly which here is considered to be a beginner's pitfall There were no typical differences in the indications for simple excision of the deposit or resection of the acromion All the patients had a long history of pain and conservative treatment had failed to relieve their symptoms The diagnosis was confirmed by a dense shadow in the region of the supraspinatus tendon on x ray examination All

tients were treated with active exercises after the operation and in some cases even before operation. In this survey of 43 shoulders no case of simultaneous cuff rupture was observed.

The age and sex distributions are listed in Table 1. Women were marginally more frequently affected than men and housewives of 45–50 years of age were the most frequent patients. This corresponds with the reports of DePalma & Kruper (1961), Hammond (1962) and Howorth (1945).

## RESULTS

The results of operative treatment are listed in Table 2. Thirty four out of 43 operations were successful. One of the failures had new bone formation at the resected acromion (Figure 1). One of the patients in Group B with an excellent final result at first had only a removal of the calcific deposit, but the symptoms were not relieved until his acromion was resected later on. In Group C one of the patients with a good result did not obtain this before his acromion had been resected twice.

*Table 1. Age and sex distributions in 38 patients (43 shoulders) treated by operation*

| Age | Men | Women | Total |
|---|---|---|---|
| 30–40 | 3 | 4 | 7 |
| 40–50 | 8 | 11 | 19 |
| 50–60 | 3 | 10 | 13 |
| 60–70 | 2 | 1 | 3 |
| 70–80 | 1 | – | 1 |
| | 17 | 26 | 43 |

*Table 2. Classification of the results of 43 operated shoulders in 38 patients*

| Results | Group A Excision of calc. dep. | Group B Resection of acromion + calc. dep. | Group C Resection of acromion alone |
|---|---|---|---|
| Excellent | 6 | 12 | 2 |
| Good | 4 | 8 | 2 |
| Poor | 2 | 6 | 1 |
| | 12 | 26 | 5 |

The period of observation varied from 3 months to 14 years (average 3.2 years). The stay in hospital varied from 5–104 days (average 33

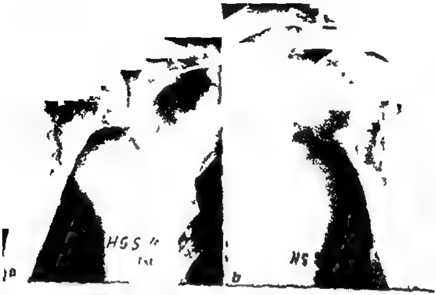



*Figure 1 (a) Calcific tendinitis of the right supraspinatus tendon in a 60 year old man (b) Left shoulder in the same patient Removal of the deposit and resection of the acromion were performed bilaterally (c) Symptomatic new bone formation in the left shoulder*

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From this study the author believes that the minor procedure of simple removal of the deposit is to be preferred except where the large group of patients who have increased pain in the middle range of abduction are concerned In these cases resection of the acromion is the most logical procedure, and it has proved to be beneficial Removal of the deposit at the same time cannot do any harm, since the subdeltoid bursa probably should be opened anyhow to exclude or repair contemporary cuff rupture Section of the coracoacromial ligament is probably of value in a few cases where there is marked thickening of the cuff and bursa True snapping of this ligament has been observed at operation on one occasion recently

## SUMMARY

Forty three shoulders in 38 patients have been reviewed They were all operated on for long standing incapacitating calcific tendinitis in the region of the supraspinatus tendon Excellent or good results were obtained in 34 out of 43 shoulders The methods employed were simple incision and curettement in 12 shoulders, curettement combined with partial resection of the acromion in 26 shoulders, and resection of the acromion in 5 shoulders The results were the same in these three groups and about 80 per cent of the operations were successful The most commonly affected patients were women of 45–50 years of age

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days) This long hospitalization was due to the postoperative training with physiotherapy

The symptoms had lasted from 8 months to 22 years (average 7 years) prior to the operation The pain disappeared from immediately to 6 months after operation (average 2 4 months) Normal motion of the shoulder (patients' evaluation) was achieved from 2 weeks to 1 year after operation (average 3 5 months) The patients in Group A had a much easier and shorter convalescence than the others There were no serious complications resulting from the operative treatment

## DISCUSSION

Bearing in mind that all the patients were chronic cases in whom conservative treatment had failed, it seems that the results are favourable The results were the same in all three groups, about 80 per cent of the operations were successful Bruusgaard (1952) reported favourable results in all his 22 patients after partial resection of the acromion

Watson-Jones (1955) proposed this operation for calcific tendinitis in 1939, but in the form of total acromionectomy Armstrong (1949) reported harmful new bone formation at the osteotomy site after partial resection of the acromion He reported unsatisfactory results in five out of nine patients and therefore abandoned this method in favour of complete acromionectomy, which, according to him, gave better results Harmon (1958) and Hammond (1962) too were in favour of complete acromionectomy McLaughlin & Nevasier (Hammond 1962) disagreed regarding the necessity for complete acromionectomy, and believed the section of the coracoacromial ligament to be more important In this survey there are no cases of complete acromionectomy to compare with partial resection However, in contrast to Armstrong (1949), we have seen symptomatic new bone formation at the osteotomy site in only one out of 31 cases

From Table 2 it might be concluded that leaving the deposit *in situ* does not influence the final result after partial resection of the acromion This feature is supported by Hammond (1962)

Simple incision and curettement of the calcific deposit, which was first performed by Harrington & Codman in 1902 (Howorth 1945), obviously is a minor procedure requiring only a short convalescence This method has adherents such as McLaughlin (1946), Moseley (1963), DePalma & Kruper (1961) and Howorth (1945) DePalma & Kruper state that they also divide the coracoacromial ligament It might also

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*Key words* peritendinitis, calcific tendinitis supraspinatus tendinitis tendinitis

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Acta orthop scand 46 211–215 1975

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# EWING's SARCOMA SIMULATING VERTEBRA PLANA

J O Poulsen, J T Jensen & P Thommesen

Accepted 16 xi 74

When found as an isolated phenomenon, vertebra plana is mostly regarded as eosinophilic granuloma (Compere et al 1954, Ochsner 1966) and healing is expected spontaneously with almost complete regeneration

Recently we had a typical case of vertebra plana caused by Ewing's sarcoma, and we have looked over cases and x rays concerning three patients with spontaneously healed vertebra plana and one with Ewing's sarcoma localized in the spine with special reference to the symptoms which led to their seeking medical advice and the results of x ray examinations at the first visit The purpose has been to examine the possibilities of being able to distinguish between the two conditions

## CASE REPORTS

*Case 1*

A 9 year-old boy was referred to hospital with low back pain X ray showed collapse of the fifth lumbar vertebral body with adjacent discs intact (above and below) No soft tissue swelling. A skeletal survey revealed no additional lesions (see Figure 1) ESR 30 mm per hour Diagnosis eosinophilic granuloma Ten years later the vertebral body was completely regenerated (Figures 1–4)

*Case 2*

A 4 year old boy who 1 month previously had fallen down from a table with ensuing pain in the back X ray films showed collapse of the tenth thoracic vertebral body with adjacent discs intact No soft tissue swelling Skeletal survey showed no additional lesions ESR 8 mm per hour Diagnosis eosinophilic granuloma Fourteen years later the x ray films showed almost complete rebuilding of the vertebral body

*Case 3*

A 12 year-old boy who six months before sustained an adequate trauma while diving X ray films showed some degree of collapse of the 4th thoracic vertebral

body. Constant back pain led to a new examination. X-ray film showed increased collapse of the vertebral body with adjacent discs intact. No soft tissue swelling. The skeletal survey revealed no additional lesions. ESR 8 mm per hour. Diagnosis: eosinophilic granuloma. X-ray films 15 years later showed almost complete regeneration of the vertebral body.

*Case 4*

A 9-year-old girl who for 3 months had pain in the right leg. X-ray of the lumbar spine showed irregular collapse of the fifth lumbar vertebral body with soft tissue mass with scanty calcification. ESR 30 mm per hour. Surgical biopsy established the diagnosis of Ewing's sarcoma. The patient died ten months later (Figure 6).

*Case 5*

A 2-year-old boy who for 1 month had pain in both legs and difficulty in walking. X-ray showed collapse of the 4th lumbar vertebral body with adjacent discs intact. No soft tissue swelling (Figure 5). Skeletal survey revealed no additional lesions. ESR 19 mm per hour. Fine needle aspiration biopsy: atypical reticel cells but no sign of malignancy. Final diagnosis: eosinophilic granuloma. In spite of adequate treatment he developed paresis in both legs. Surgical biopsy established the diagnosis Ewing's sarcoma. Revision of aspiration biopsy showed no sign of malignancy.

## DISCUSSION

These symptoms do not differ essentially from, and are very much like, earlier descriptions of vertebra plana. However in two cases it was a trauma that led the patients to the doctor. ESR varied from 8–30 mm per hour. X-ray showed a varying degree of collapse (Figures 1, 5 and

*Figure 1. The x-ray film shows vertebra plana in the fifth lumbar vertebra with partial collapse of the body.*

*Figure 2. X-ray film from the same patient (case 1) 8 months later. Complete collapse of the fifth lumbar vertebra.*

*Figure 3. X-ray film 1 year later (same patient). A considerable regeneration of the vertebral body has taken place.*

*Figure 4. X-ray film 8 years later (same patient). Complete regeneration of the vertebral body.*

*Figure 5. The x-ray film shows vertebra plana in the fourth lumbar vertebra (case 5) and at least three of Compere's four criteria are fulfilled (see text).*

*Figure 6. The x-ray film shows vertebra plana in the fifth lumbar vertebra with soft tissue swelling and scanty calcification (case 4).*

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*Key words* Calvé's disease vertebra plana eosinophilic granuloma, bone tumours spine Ewing's sarcoma

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6) The case primarily diagnosed as eosinophilic granuloma (Figure 5) *fulfilled at least three or four of the criteria, on x-ray, which Calvé (1926) has laid down for vertebra plana These criteria have later been used in the diagnosis of eosinophilic granuloma* (Compere et al 1954)

1) *Only one vertebra involved*

2) Adjacent discs intact above and below the diseased vertebra

3) *Disc space about a third wider than the next space above and below*

4) *The claim concerning homogenous density of the vertebral body* was perhaps not quite fulfilled because retrospectively one has to acknowledge a certain irregular structure of the bone (cf Figure 2 and Figure 5) On the other hand there was no soft tissue swelling around *the vertebra as seen clearly on Figure 6 Fine needle aspiration biopsy* did not contradict the diagnosis; even after revision and it was only *aggravation of the condition* that led to open surgical biopsy Hereby the diagnosis Ewing's sarcoma was established This malignant tumour is only localized primarily in the spine in 1–2 per cent of cases (Dahlin et al 1961)

However a case of "a highly malignant undifferentiated sarcoma in *the tenth thoracic vertebra* in an 8-year-old patient causing vertebra plana has been reported by Hillmann (1954), and this together with the present case emphasizes that the diagnosis eosinophilic granuloma as a cause of vertebra plana cannot be made on the history or by a characteristic x-ray but only by surgical biopsy (Fowles & Bobechko 1970)

## SUMMARY

Five cases of vertebra plana have been reported, three with spontaneous regeneration and two caused by Ewing's sarcoma It is emphasized that the diagnosis eosinophilic granuloma must rely on surgical biopsy

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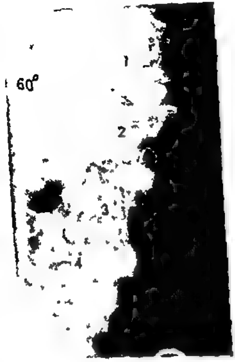


*Figure 1 Case 1 Operative discogram in a patient with a lumbar scoliosis measuring 60° in the sitting position Discograms taken at the L12 L23 and L34 levels Note the globular intact appearance of the disc which has migrated towards the convex side of the curvature*

and an antero-posterior radiograph taken on the table before disc excision and instrumentation

The progressive stages in severity of the intervertebral disc changes are typified by the following three examples

## CASE REPORTS

### Case 1

A 16 year old female had acute *poliomyelitis* when aged 3 years When she was 12 years old a lumbar scoliosis was detected which measured 45° and had progressed only 15° over the past 4 years Operative discograms were done at L12 L23 and L34 levels (Figure 1) The nuclei had migrated to the convex side of the curvature they were normal in *shape and* the volumes injected measured from 0.9 to 1 ml There were no gross vertebral body changes other than the rotation present

### Case 2

A 12 year old *female* had had a paralytic lumbar scoliosis for ten years It had progressed rapidly from 80 to 100° over the previous 12 months. Operative discography was done at the L12 L23 and L34 levels (Figure 2) The nuclei accepted from 0.6 to 1 ml of the radio opaque *medium* They had migrated further towards the convexity of the curvature where the annulus fibrosus is thinner than normal

Acta orthop. scand. 46, 216–220, 1975

The Department of Orthopaedic Surgery, The University of Hong Kong, and The Duchess of Kent Children's Orthopaedic Hospital, 12 Sandy Bay Road, Hong Kong

# DISCOGRAPHY IN PARALYTIC SCOLIOSIS

## *The Progressive Displacement of the Nucleus Pulposus*

JOHN PATRICK O'BRIEN*, ANTHONY P. DWYER** & ARTHUR R. HODGSON***

*Accepted 25 x 74*

The purpose of this paper is to demonstrate the progressive macroscopic alterations, as visualised by discography, of the intervertebral disc in patients with paralytic scoliosis.

Lumbar discography was described by Lindblom in 1948 as a means of investigating the causes of low back pain and sciatica. Percy in 1961 performed discography in a patient with idiopathic scoliosis. The nucleus pulposus at the apex had shifted to the convex side of the deformity. He concluded that this may be a congenital anomaly responsible for the scoliosis.

Kazmin et al. (1969) used operative discography to demonstrate the displacement of the nucleus pulposus. Del Torto (1968) demonstrated with discography the persisting lateral displacement of the nucleus in scoliosis after surgery.

### MATERIAL AND METHODS

Ten patients with paralytic scoliosis had discograms done at the time of Dwyer's anterior instrumentation. There were five males and five females, the average age at the time of surgery was 14 years. All the scolioses were thoraco lumbar or lumbar in type.

During the routine anterior approach to the spine, the discs at the apex of the curve were identified and a 2 ml syringe used to inject Hypaque sodium 50 per cent (Winthrop), a water soluble radio opaque medium, into the nuclei of two or three intervertebral discs at the apex of the curve. The volume of dye injected was noted

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*Figure 3 Case 3 A severe paralytic scoliosis in a 12 year old male Operative discograms done at the apex of the deformity (D12 L1 and L12) Note the extreme rotation at the apex of the curvature also thinning of the convex annulus fibrosus and the marked excavation of the adjacent aspects of the vertebral bodies*

Compression of the nucleus against the annulus fibrosus in this situation is responsible for thinning of the annular fibres presumably by pressure atrophy (Figure 2, L23 level) Another feature observed in the more severe curves is scalloping of the vertebral bodies adjacent to the nucleus pulposus (best seen in Figure 3)

These changes in the intervertebral disc and adjacent vertebral bodies are secondary phenomena, the primary defect being muscle imbalance

The volume and contour of each nucleus is within normal limits and in none of the discograms done have degenerative patterns been observed

## SUMMARY

Observations are made on the progressive alterations of the intervertebral disc in paralytic scoliosis, demonstrated by discography

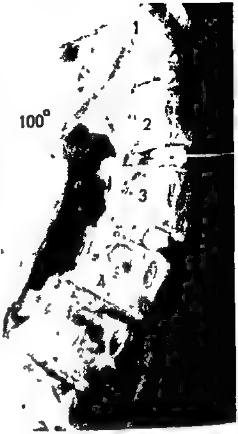


*Figure 2 Case 2 A lumbar scoliosis, more severe and more long standing, in a 13-year-old female, measuring 100° in the sitting position Operative discograms have been done at the L12, L23 and L34 levels Note the increase in rotation and the further migration of intact nuclei towards the convexity Note also the early scalloping of the vertebral bodies adjacent to the nuclei with thinning of the annulus fibrosus on the convexity*

especially at the L23 level Rotation of the vertebral bodies at the apex was more marked and there was early scalloping of the lower surface of the third lumbar vertebral body in contact with its corresponding nucleus pulposus

*Case 3*

A 12 year old male had acute poliomyelitis when 10 months of age, a scoliosis developed immediately after the acute illness, and at the time of operation measured 126° (Figure 3)

Operative diagrams were done at two levels, D12 L1 and L12 (Figure 3) The former nucleus accepted 0 6 ml and the latter 0 7 ml of radio opaque dye The nuclei were not degenerative but they had migrated even further to the convex side of the deformity and again there was apparent thinning of the annulus fibrosus adjacent to the displaced nucleus The rotation of the vertebral bodies was extreme and their excavation by the nuclei was marked Osteoporosis was also more evident than in the radiographs of the previous two patients

## DISCUSSION

With increasing deformity in scoliosis, the nucleus pulposus is displaced more and more towards the convexity of the curvature


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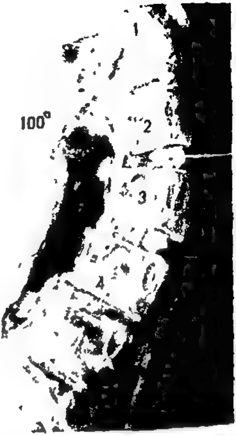


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With increasing deformity in scoliosis, the nucleus pulposus is displaced more and more towards the convexity of the curvature


*Figure 3 Case 3 A severe paralyt c scoliosis in a 1? year old male Operative discograms done at the apex of the deformity (D12 L1 and I 12) Note the extreme rotation at the apex of the curvature also thinning of the convex annulus fibrosus and the marked excavation of the adjacent aspects of the vertebral bodies*

Compression of the nucleus against the annulus fibrosus in this situation is responsible for thinning of the annular fibres presumably by pressure atrophy (Figure 2 L23 level) Another feature observed in the more severe curves is scalloping of the vertebral bodies adjacent to the nucleus pulposus (best seen in Figure 3)

These changes in the intervertebral disc and adjacent vertebral bodies are secondary phenomena the primary defect being muscle imbalance

The volume and contour of each nucleus is within normal limits and in none of the discograms done have degenerative patterns been observed

SUMMARY

Observations are made on the progressive alterations of the inter vertebral disc in paralytic scoliosis demonstrated by discography

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*Key words* spine, scoliosis, discography intervertebral disc, poliomyelitis nucleus pulposus

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# PHYSIOLOGICAL GENU VARUM

Lars Ingvar Hansson & Mohammed Zayer

Accepted 15.x 74

The lower extremities of the newborn child are normally somewhat bent in the sagittal and frontal plane (Bohm 1928 Forrest 1949) usually combined with inward torsion of the whole extremity or the tibia (Blount 1966) Normally there is a certain genu varum at birth this usually disappears during the first or second year of life During the third or fourth year it often changes to genu valgum which dis appears at about six years of age (Bohm 1928 Bragard 1932 Renotte 1968)

Some children have a more pronounced genu varum with spon taneous correction later than normal The deformity is often referred to as physiological or developmental genu varum (Sharrard 1971) and can create differential diagnostic d fficulties and be hard to distinguish from various pathological forms of genu varum

Various causes have been mentioned or physiological genu varum (Myers 1948 Jacobsson 1949 Kite 1954 de Palma 1955 Bateson 1966 Shan ls & Raney 1967) Blount (1966) asserted that the spontaneous correction of physiological genu varum is due to the varus position stimulating the growth on the medial side of the proximal tibia

It has earlier been found that there is a connexion between physio logical genu varum and the infantile type of Mb Blount (Langenskiold 1952 Golding & McNeil Smith 1963 Langenskiold & Riska 1964 Blount 1966 Zayer 1973) The present work investigates this connexion in closer detail

## MATERIAL AND METHODS

In an in est gation of Mb Blount (Zayer 1973) material was collected from 180 pat ents w th pronounced genu varum who were suspected of having Mb Blount They were collected from orthopaed c paed atric and roentgenolog cal cl nics throughout Sweden The nvest gation was made cl nically and roentgenologically on repeated occas ons from childhood to in most cases adult ages

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3 a

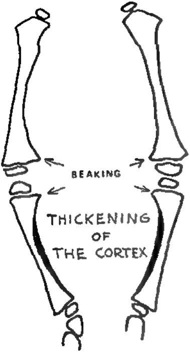



*Figure 3 Physiological genu varum at the age of 1 year 8 months with typical roentgenological changes in the distal femur and the proximal tibia*

3 b

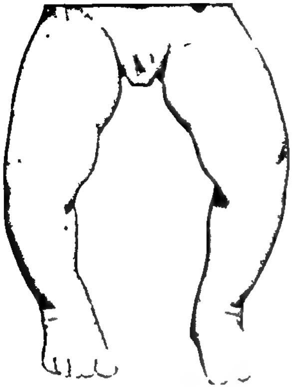


*Figure 1*
*Physiological genu varum at 1 year 8 months*

*(Figures 1–[illegible] depict the same patient.)*

*Figure 2 Genu valgum at [illegible] years 8 months*

*Figure 4 Genu valgum at 9 years 8 months The roentgen examination shows normal conditions*

for varying lengths of time In five, boots or night splints were prescribed One was put into plaster bilaterally at almost two years of age In three, the varus deformity was corrected with the aid of a bilateral tibial osteotomy at the age of 1½–2 years Unilateral stapling according to Blount was performed in one patient in the lateral part of the proximal tibia at almost three years of age This operation had no positive effect on the varus position probably because of poor attachment of the staple Both the operated and the non-operated side underwent the same correction

In the 11 cases, where there was physiological genu varum on one side and Mb Blount on the other, the metaphysial stage (see below) was present roentgenologically in all cases, whereas one case progressed to the epiphyseal stage (Figures 5–8) Of these, only one at the metaphysial stage was corrected by osteotomy through the proximal tibia The other side with physiological genu varum was not treated

## DISCUSSION

The most important differential diagnoses of physiological genu varum are Mb Blount, prenatal genu varum, healed rachitis, hypophosphataemia, and post traumatic genu varum after physial injury

RESULTS

At a follow-up of the cases, 85 were diagnosed as Mb Blount, of which 52 were of the infantile type and 33 of the juvenile type, 76 were diagnosed as bilateral physiological genu varum and 19 showed a different pathological genesis. Of the 52 with infantile Mb Blount, 11 had Mb Blount on one side and physiological genu varum on the other. Thus the final material consisted of 76 cases with bilateral physiological genu varum and 11 with unilateral physiological genu varum.

*Course*

Of the physiological genu varum cases 58 were boys and 29 were girls. In all of them, a varus deformity in the knee joints was recorded at birth. This deformity increased during the latter part of the first year of life and when the child began to walk. The varus deformity was usually most pronounced in the first and second year of life. It could then amount to 30–40 degrees at clinical investigation (Figure 1). The deformity was successively reduced during the following year and most often was eliminated between the ages of three and five in both boys and girls. In nine instances, during the following years up to the age of 11, a lesser valgus position (Figure 2) arose, this often remained.

In 28 cases, there is information regarding a similar varus deformity during childhood in the parents, siblings, or close relatives. There was no difference in the course of those with bilateral physiological genu varum and the 11 with unilateral physiological genu varum.

*Roentgen*

All cases showed a medio-dorsal beaking in the metaphysis of femur and tibia, thickening of the medio-dorsal cortex, and some reduction in the size of the bone epiphysis of the distal femur. The medial parts of the bone epiphysis of the proximal tibia and also the bone epiphysis of the distal femur were often wedge-shaped, the wedge pointing medially (Figure 3). These changes were present between the ages of one and two years and differed from the normal roentgen picture, as shown by Scheller (1960). During the following years, the roentgenological picture gradually became normal (Figure 4).

*Treatment*

In 63 out of 87 cases, different degrees of pes planu-valgus were recorded, in 19, this was treated with supports of varying types and

*7 a (Right)*

*7 b (Left)*

*8 (Left)*

*Figures 5 8 Roentgen examination of a patient with right sided physiological genu varum and left sided Mb Blount at different ages and different stages*

*Figure 5 1 year 6 months*
*a Physiological genu varum*
*b Mb Blount—initial stage*

*Figure 6 2 years*
*a Physiological genu varum*
*b Mb Blount—metaphysial stage*

*Figure 7 4 years*
*a Normal*
*b Mb Blount—metaphysial stage*

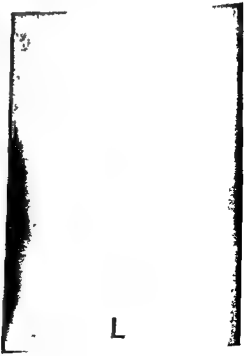
*Figure 8 7 years 2 months*
*Mb Blount epiphysial stage*

Mb Blount is a growth disturbance localized to the postero-medial part of the proximal tibia, where it disturbs the growth in the metaphysis the physis, and the bone epiphysis The infantile type is usually bilateral and generally *found when the child begins to walk*, whereas the juvenile type is usually unilateral and has its debut between the


*5 a (Right)*


*5 b (Left)*


*6 a (Right)*




*6 b (Left)*

genu varum is the reversible initial stage at Mb Blount, because both physiological genu and Mb Blount can occur at the same time in the same patient

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*Key words* bone diseases developmental epiphyses growth disorders knee tibia

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ages of 6 and 14 years The infantile type goes through four roentgenological stages, initial, metaphysial, epiphysial, and adult (Zayer 1973). Before the age of two, it is impossible to distinguish cases of physiological genu varum from the initial stage of Mb Blount (Golding & McNeil-Smith 1963, Blount 1966, Zayer 1973) Physiological genu varum can well be a reversible pre-stage of Mb Blount The latter opinion is supported by the results in the present investigation, where in 11 cases Mb Blount was present on one side and changes indicating physiological genu varum on the other side

In prenatal genu varum (Caffey 1967), however, there are less difficulties of differential diagnostics in distinguishing it from physiological genu varum because the varus deformity is already pronounced at birth, and there is a dimple on the convex curvature of the lower leg The varus position is usually present up to the age of 2 years, and roentgenologically, it can then resemble healed rachitis, Mb Blount and physiological genu varum

The healed rachitis creates differential diagnostic difficulties because the varus deformity of this condition remains and can resemble physiological genu varum or Mb Blount

In hypophosphataemia, a varus deformity is present in both the femur and tibia The growth zones are in addition thicker and irregular, and on the roentgen picture, the structure is coarse and irregular From the laboratory standpoint, this condition shows characteristic features

Post-traumatic genu varum most often arises after longitudinal trauma The varus deformity is then frequently unilateral and does not usually appear during the first years of life

As a rule, it is not necessary to introduce any type of treatment for physiological genu varum In the present material, all cases became normal, irrespective of whether or not they were treated On the other hand, it is important to investigate and follow-up children with genu varum so that a pathological genesis can be excluded

## SUMMARY

Physiological genu varum is a condition which, during the first years of life, usually does not require any treatment, but it can present differential diagnostic difficulties The condition can be distinguished from Mb Blount, prenatal genu varum, hypophosphataemia, rachitis, and post-traumatic genu varum in its course, roentgenological picture, and laboratory examination It is highly probable that physiological

genu varum is the reversible initial stage of Mb Blount, because both physiological genu and Mb Blount can occur at the same time in the same patient

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Acta orthop scand 46, 230-233, 1975

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# STRANGULATED LUMBAR HERNIA AND VOLVULUS FOLLOWING REMOVAL OF ILIAC CREST BONE GRAFT

## *A Case Report*

J H CHALLIS, J. A LYTTLE & A E STUART

Accepted 17 x 74

The first occurrence of herniation through an iliac bone defect was reported by Oldfield in 1945 Since then, twelve cases have been described in the literature (see reference list) The majority followed removal of bone from the ilium for the purpose of bone grafting, although in one case the iliac bone defect followed military shrapnel injury (Lewin & Bradley 1949) and in a second the bone was removed in the treatment of osteomyelitis (Bosworth 1955) The earliest reported occurrence of a hernia was 3 months after the removal of iliac bone (Parisel & De Marneffe 1958, Penneman & De Marneffe 1968, Reid 1968), but the patients usually presented years later (Lotem et al 1971, Pyrtek & Kelly 1960) The usual presentation was an iliac swelling, sometimes associated with local pain One case presented with symptoms of partial bowel obstruction and a second had intermittent episodes of small bowel obstruction In no instance was the viability of the viscera seriously threatened

The present report describes acute intestinal obstruction with strangulation following internal herniation through the iliac crest defect, 1 month after taking iliac bone grafts

### CASE REPORT

An 88 year old female had suffered from rheumatoid arthritis for many years An arthrodesis of the left wrist was performed using the right iliac crest as the donor site The technique for taking the graft was as follows

The subcutaneous border of the anterior third of the iliac crest was defined and the muscles elevated sub periostally from both surfaces A full thickness graft 8 × 2 cm was cut with a reciprocating saw (Figure 1) Haemostasis was obtained with diathermy and bone wax and a suction drain inserted The origins of the

*Figure 1 Lateral X ray of right iliac crest showing bone defect*

*Figure 2 Abdominal X ray showing distended small intestine and soft tissue swelling over right pelvis*

trunk muscles were sutured to gluteus maximus and tensor fascia lata with interrupted braided silk and the fat and skin closed with interrupted sutures

Twenty four days after operation the patient developed abdominal pain with vomiting but no change in bowel habit

On examination she was afebrile had no abdominal tenderness or guarding and normal bowel sounds were present. Over the next 2 days her symptoms recurred. there was a little abdominal distension but no tenderness and no fever Abdominal X rays (Figure 2) showed moderately distended coils of jejunum and ileum with an occasional fluid level As her condition failed to improve laparotomy was undertaken 2 days later The immediate finding was distended coils of small gut These were congested and on examination of the mesentery a 270° anticlockwise volvulus was found The condition of the bowel recovered on de-rotation The caecum and 1 foot of terminal ileum was found to be collapsed and the latter was traced to

Acta orthop scand 46, 230–233, 1975

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If possible only half the thickness of the crest should be taken, but if a full thickness graft is needed, then the defect should be carefully repaired with adjacent muscles and if these are inadequate further steps such as the transposition of the anterior iliac spine or tantalum wire mesh should be considered There seems no reason why self-curing Acrylic cement should not provide a simple and safe substitute for the excised graft


## SUMMARY

A case of a woman aged 88 years with a volvulus and strangulated small bowel in a hernia following removal of iliac crest for bone grafting is described Emphasis is laid on prevention of an incisional hernia when obtaining the bone graft



## ACKNOWLEDGEMENTS

We wish to thank Mr Brian Roper for permission to report his case


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*Key words* hernia iliac crest graft


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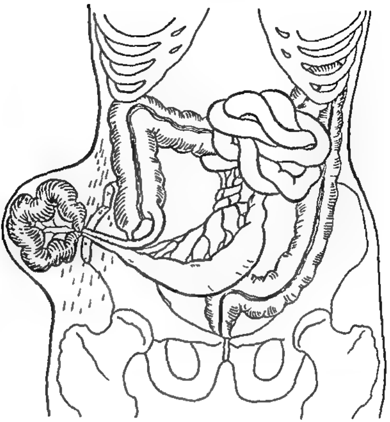

*Figure 2 Drawing showing small bowel volvulus and strangulated iliac hernia*

a 1 cm hole in the peritoneum adjacent to the right iliac crest (Figure 3) The defect was enlarged with scissors and a large cavity was found, lateral to the iliac crest, containing 2 feet of necrotic small bowel The peritoneal defect lay just medial to the bone donor site The necrotic small gut was resected and an end to end anastomosis was carried out, with repair of the peritoneal defect

The abdomen was closed with a tube drain lateral to the iliac crest The patient made a slow but uneventful recovery

## DISCUSSION

Iliac bone grafts, either full thickness or partial thickness, are frequently used in orthopaedic surgery Herniae following removal of iliac bone grafts are rare but it would seem likely that the larger the bone defect and the poorer the muscles, the greater would be the chance of such a hernia developing The patient described was elderly, obese, and had very poor musculature

Although herniae after iliac crest grafts are rare, the orthopaedic surgeon should take active steps to prevent their occurrence in the cases at particular risk, for example the elderly with poor musculature

If possible only half the thickness of the crest should be taken, but if a full thickness graft is needed, then the defect should be carefully repaired with adjacent muscles and if these are inadequate further steps such as the transposition of the anterior iliac spine or tantalum wire mesh should be considered There seems no reason why self-curing Acrylic cement should not provide a simple and safe substitute for the excised graft

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Acta orthop scand 46, 234–245 1975

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# THE ROENTGENOLOGICAL END RESULTS AFTER CALIPER TREATMENT OF COXA PLANA WITH VARYING DEGREES OF EPIPHYSEAL INVOLVEMENT

SVEN FRIBERG

Accepted 23 xii 74

When the major reports of the roentgenological results after various forms of treatment for Legg-Calvé-Perthes disease or Coxa Plana are compared no method is found to be clearly superior to the others (Table 1) A possible explanation for this apparent similarity in the results of the various forms of treatment could be that the disease has a predestined course that is not decisively altered by treatment The lack of major differences in the results could also be due to insufficient classification of the disease and a different representation of patients in the various materials Support for the latter theory can be found from the observations made by O'Garra (1959), and further evaluated by Catterall (1971, 1972), that deformation of the proximal femoral epiphysis is rare in cases where only isolated segmental necrosis occurs This observation suggests that the primary involvement of the epiphysis by the necrotic process might have a strong influence on the roentgenological results For a relevant and comparable evaluation of results after treatment of Coxa Plana it would then be necessary to take into consideration the extent of primary necrosis in each individual case

This paper reports the results after caliper treatment (Thomas' splint) of patients with Coxa Plana The extent of epiphyseal involvement in each individual case has been taken into account The aim was to study if the degree of necrosis of the epiphysis had any influence on the roentgenological end result

## MATERIAL AND METHODS

During the period 1959 to 1970 45 hips with Coxa Plana in 39 patients were treated with calipers in the form of Thomas splints at the department of Orthopaedic Surgery at the University Hospital in Umeå Sweden

*Table 1 Radiographic results after various forms of treatment*

| Investigator | No of cases | Treatment | Results in % | | |
|---|---|---|---|---|---|
| | | | good | fair | poor |
| *Treatment by non weightbearing* | | | | | |
| Mindell & Sherman (1951) | 28 | bed rest | 53 | 18 | 29 |
| Herndorn & Heyman (1952) | 33 | bed rest | 61 | 39 | 0 |
| Helbo (1953) | 61 | bed rest | 82 | 16 | 2 |
| Hauge (1957) | 132 | bed rest | 33 | 40 | 27 |
| Evans & Loyd Roberts (1958) | 52 | bed rest | 29 | 40 | 31 |
| Katz (1967) | 112 | traction + bed rest | 53 | 27 | 20 |
| Range of results after bed rest | | | 29–82 | 16–40 | 0–31 |
| Evans & Loyd Roberts (1958) | 24 | crutches + Snyders sling | [illegible] | 17 | 25 |
| Mindell & Sherman (1951) | 32 | crutches + caliper | 72 | 16 | 12 |
| Wansbrough et al (1959) | 76 | caliper (Taylor) | 75 | 12 | 13 |
| Wansbrough et al (1959) | 16 | caliper (Thomas' splint) | 25 | 50 | 25 |
| Mose (1964) | 71 | caliper | 45 | 17 | 38 |
| Range of results after crutches or caliper | | | 25–75 | 12–50 | 12–38 |
| *Treatment by containment of the head* | | | | | |
| Katz (1967) | 110 | brace and bed rest | 48 | 46 | 6 |
| Harrison et al (1969) | 12 | splint | 28 | 36 | 36 |
| Petrie & Bitenic (1971) | 60 | plaster of Paris | 60 | 31 | 9 |
| Catterall (1972) | 36 | splint | 50 | 22 | 28 |
| Range of results after conservative treatment | | | 28–60 | 22–46 | 6–36 |
| Craig & Pinder (1969) | 100 | subtrochanteric osteotomy | 43 | 39 | 18 |
| Canale et al (1972) | 23 | pelvic osteotomy | 33 | 47 | 20 |
| Axer et al (1973) | 32 | subtrochanteric osteotomy | 53 | 13 | 3 |
| Haraldsson (1973) | 12 | subtrochanteric osteotomy | 75 | 25 | 0 |
| Range of results after operative treatment | | | 33–75 | 13–47 | 0–20 |
| *Symptomatic treatment* | | | | | |
| Catterall (1972) | 95 | | 57 | 19 | 24 |

All patients were treated with strict non weightbearing in the calipers. The children were only allowed to remove their calipers in water or in bed. A short period (1–2 weeks) of bed rest with traction was used initially if acute symptoms were present at the time of the diagnosis. The mean duration of treatment was 2.4 years (0.5–4.5).

The material was grouped (1–4) according to the degree of involvement of the epiphysis as outlined by Catterall (1972). The criteria for the different groups are given in Figures 1 and 2. The distribution of patients in the different groups in relation to age and sex is shown in Figure 3.

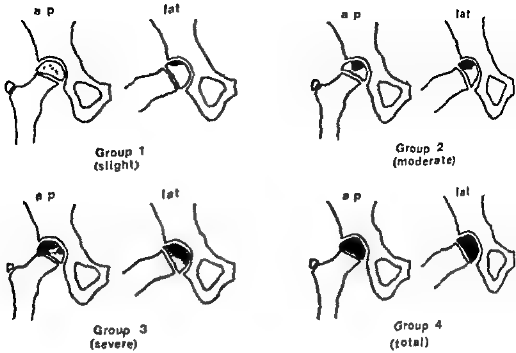



*Figure 1 Schematic drawings of the radiological features in the various groups with different degrees of epiphyseal involvement*

The roentgenological results were studied when a definite normalization of the bone structure in the epiphysis had occurred Classification of the results was made both from a "general assessment of the radiographs" according to Catterall (1972) (Figure 4) and by calculation of the epiphyseal and joint surface quotients (Figure 5) (Heyman & Herndon 1950 Eyre Brook 1936 Meyer 1966) The mean period of time between diagnosis and the radiological assessment was 3 2 years (1 6–5 2)

## RESULTS

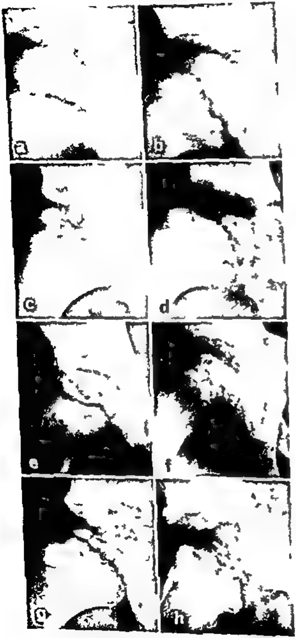
### *Total material*

The "general assessment of the radiographs" gave good results in 33 per cent, fair in 45 per cent and poor in 22 per cent of the cases No major differences in the results were found when using the three different methods (general assessment, epiphyseal quotient and joint surface quotient) for the evaluation (Table 2)

### *Groups with varying involvement of the epiphysis (1–4)*

A definite classification according to the epiphyseal involvement was possible in all cases in the fragmentation stage of the disease Subsequent radiographic examinations did not lead to a change of classification The relationship between the degree of involvement of the

*Antero poster or (a p) view* *Lateral view*



*Group 1 (Slight involvement) The changes are confined to the antero-superior part of the epiphysis In the a p view only a slight cystic appearance is visible The lateral view shows the changes in the antero superior part of the epiphysis*

*Group 2 (Moderate involvement) Complete involvement of the anterior part of the epiphysis The a p view shows that the lateral and medial part of the epiphysis have escaped involvement In the lateral view the complete involvement of the anterior part is illustrated*

*Group 3 (Severe involvement) The major part of the epiphysis is involved Only the postero medial part of the epiphysis shows normal bone structure*

*Group 4 (Total involvement) No normal bone structure is visible in the entire epiphysis*

*Figure 2 Radiological features for classification of cases into the various groups according to epiphyseal involvement (All cases shown are in the fragmentation stage of the disease)*

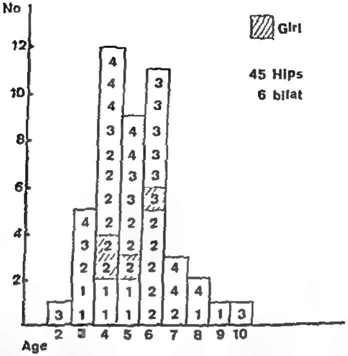



*Figure 3 Age and sex distribution (The degree of epiphyseal involvement is indicated by Arabian numerals)*


| *Good result* | *Fair result* | *Poor result* |
|---|---|---|
| *An almost normal head—round with minimal or no compression of the epiphysis* | *A round head with moderate loss of epiphyseal height and not completely contained in the acetabulum up to one fifth being uncovered* | *A flattened and irregular head with more than one fifth uncovered by the acetabulum* |

*Figure 4 Criteria for the general assessment of the radiographs*

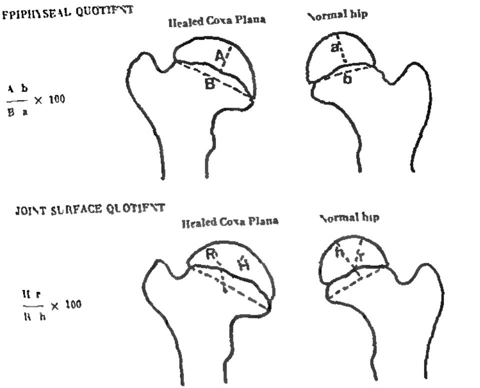



*Figure 5 Methods for assessment of epiphyseal and joint surface quotients*

*Table 2 Results—Total material*

| | General assessment of radiographs | Epiphyseal quotient | Joint surface quotient |
|---|---|---|---|
| No of hips | 45 | 33 | 33 |
| Good | [illegible] % | (> 85) 27 % | (> 85) 36 % |
| Fair | 45 % | (85–60) 39 % | (85–70) 34 % |
| Poor | [illegible] % | (< 60) 35 % | (< 70) 30 % |

epiphysis (group 1–4) and the result expressed in terms of "general assessment of the radiographs" is illustrated in Table 3. It was found that the good results were confined to groups 1 and 2 and the poor results to groups 3 and 4. The relationship between epiphyseal involvement and epiphyseal quotient and joint surface quotient is shown in Figures 6 and 7. The statistical analysis of the values found for the

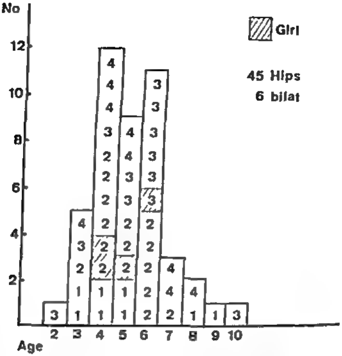



*Figure 3 Age and sex distribution (The degree of epiphyseal involvement is indicated by Arabian numerals)*


*Good result*

*An almost normal head—round with minimal or no compression of the epiphysis*

*Fair result*

*A round head with moderate loss of epiphyseal height and not completely contained in the acetabulum up to one fifth being uncovered*

*Poor result*

*A flattened and irregular head with more than one fifth uncovered by the acetabulum*

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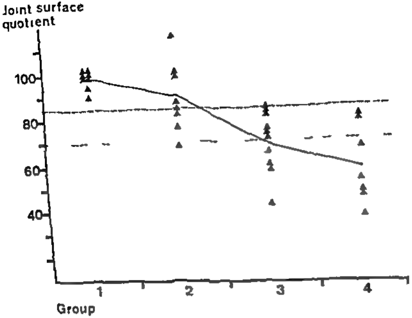


*Figure 7* *Results expressed as joint surface quotient in groups 1–4 The correlation between groups and epiphyseal quotient was 0·74 $P < 0·01$*

*Table 4 Results—Age (Results expressed in no of hips)*

| Groups 1 and 2 | Good | Fair | Groups 3 and 4 | Fair | Poor |
|---|---|---|---|---|---|
| ≤ 4 years | 9 | 2 | ≦ 4 years | 4 | 3 |
| > 4 years | 6 | 7 | > 4 years | 7 | 7 |

analysed in patients over and under 4 years of age No significant differences* could be found (Table 4)

## DISCUSSION

The radiological end results after caliper treatment (Thomas' splint) of 45 hips with Coxa Plana have been investigated When the total material is considered the results (33 per cent good, 45 per cent fair and 22 per cent poor) are similar to those reported in earlier studies

* $\chi^2$ analysis

*Table 3 Results of "general assessment of radiographs" in groups 1-4 (Results expressed in no of hips)*

| | Group 1 (slight) | Group 2 (moderate) | Group 3 (severe) | Group 4 (total) |
|---|---|---|---|---|
| *Good* | 8 | 7 | 0 | 0 |
| Fair | 0 | 9 | 8 | 3 |
| Poor | 0 | 0 | 4 | 6 |

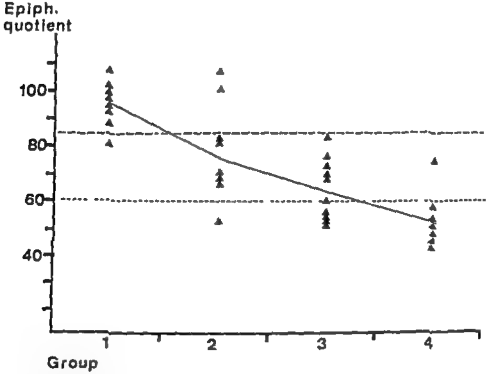


*Figure 6 Results expressed as epiphyseal quotient in groups 1–4 The correlation between groups and epiphyseal quotient was 0 74, $P < 0 01$*

epiphyseal and joint surface quotients show a strong positive correlation ($P < 0\ 01$) between the groups with more complete necrosis of the epiphysis and a higher degree of final deformity of the head

*Results in groups 1 4 — Age*

No differences* existed in the age distribution between the cases classified as belonging to the groups 1 and 2, and those in groups 3 and 4 The results in groups 1 and 2 and in groups 3 and 4 were

* $\chi^2$ analysis

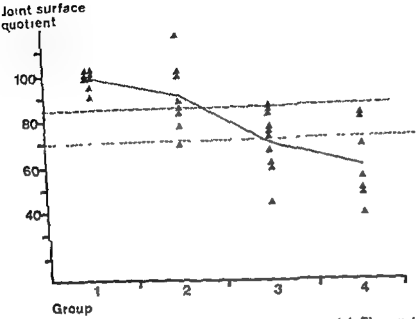


*Figure 7 Results expressed as joint surface quotient in groups 1–4 The correlation between groups and epiphyseal quotient was 0 74 $P < 0\ 01$*

*Table 4 Results—Age (Results expressed in no of hips)*

| Groups 1 and 2 | Good | Fair | Groups 3 and 4 | Fair | Poor |
|---|---|---|---|---|---|
| ≦ 4 years | 9 | 2 | ≦ 4 years | 4 | 3 |
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## DISCUSSION

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* $\chi^2$-analysis

(Mindell & Sherman 1951, Evans & Loyd-Roberts 1958, Wansbrough et al 1959, Mose 1964)

When the material was analysed with regard to the degree of primary involvement of the epiphysis according to Catterall (1972) it was found that the final deformation of the epiphysis was significantly more severe in the groups with primarily more complete necrosis of the epiphysis The contrary was found in the hips which initially showed slight alterations This is in agreement with the observations made by Catterall (1972) from an investigation of the results in the different groups of epiphyseal involvement after various forms of treatment (supervised neglect i e symptomatic treatment and periodic x ray checks, caliper, bed rest and abduction splint) The observations made by Catterall and the results of the present investigation lead to the conclusion that if different materials are to be compared it is necessary to consider the degree of epiphyseal necrosis when assessing the radiological result after treatment

In the groups with slight to moderate (groups 1 and 2) involvement of the epiphysis the results from the present investigation were satisfactory (good or fair) with no poor end results However, in the groups with severe to total necrosis of the epiphysis (groups 3 and 4) the proportion of poor end results was high in spite of the caliper treatment A direct comparison can be made between the present material and the results found by Catterall (1971, 1972) after 'supervised neglect", as the materials were grouped and the results assessed (general assessment of radiographs) according to the same principles When comparing the groups with different involvement of the epiphysis in these two studies no major difference could be found regarding the results This confirms the observation made by Catterall (1972) that caliper treatment does not show any convincing advantages over ' supervised neglect"

In the present material an even distribution of the primary groups with respect to age was found In addition the results in the groups showed no difference between patients over and under 4 years of age This contrasts with earlier reports where better end results have been claimed in the age group under 4–5 years of age (Edgren 1965, Catterall 1972)

The long-term results after Coxa Plana show that late osteoarthritis is confined to and will develop in at least fifty per cent of the cases with a poor end result (Helbo 1953, Danielsson & Hernborg 1965, Eaton 1967, Ratliff 1967, Gower & Johnston 1971) Effective treatment to

reduce the incidence of deformation must then be considered to be indicated in cases where a definite risk for a poor end result exists The satisfactory (good or fair) end results reported by Catterall (1972) after "supervised neglect" in the groups with slight to moderate involvement of the epiphysis suggest that only symptomatic treatment would be necessary in the majority of these cases In the groups with severe to total involvement of the epiphysis neither symptomatic nor caliper treatment can prevent a poor end result In these two groups a definite need for more effective treatment exists

The problem as to which treatment is the most effective in preventing deformation in Coxa Plana is still unsolved The existing reports, with few exceptions, are hardly comparable since no account has been made of the primary degree of necrosis of the epiphysis The results reported by Catterall (1972) after caliper treatment, bed rest and abduction treatment gave no definite evidence that these have any advantages over "supervised neglect" The satisfactory results (75 per cent good, 25 per cent fair) found by Haraldsson (1973) after subtrochanteric rotation and varisation osteotomies in 12 cases with severe to total involvement of the epiphysis suggested that osteotomy might be a possible method for the future However, when Marklund & Tillberg (1974) compared the results after caliper treatment and osteotomy in groups with varying degrees of epiphyseal involvement they were not able to confirm Haraldsson's observations and found no difference in the results between these two forms of treatment

## SUMMARY

The radiological results after caliper treatment of 45 hips with Coxa Plana are presented The material was grouped and analysed according to the degree of primary involvement of the epiphysis by the necrotic process It was found that the risk for deformation of the femoral head became significantly higher in the groups with more extensive involvement of the epiphysis This observation shows that the primary involvement of the epiphysis has a determining influence on the results It further indicates that if the radiographic results from different materials of Coxa Plana are to be compared consideration must be given to the primary extent of necrosis of the epiphysis

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*Key words* child, hip osteochondritis, classification, radiography, therapy

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*Key words* child hip osteochondritis classification radiography therapy

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Acta orthop scand 46 246–255, 1975

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# ACETYLSALICYLIC ACID IN A TRIAL TO DIMINISH THROMBOEMBOLIC COMPLICATIONS AFTER ELECTIVE HIP SURGERY

J Soreff, H Johnsson, L Diener & L Goransson

Accepted 23 xii 74

Thromboembolic complications after trauma as well as after elective surgery in the lower extremities and the pelvis are well documented (Sevitt & Gallagher 1959, Borgstrom et al 1965, Ahlberg et al 1968 Bergquist et al 1972) The incidence of complications such as these has been reduced by prophylactic treatment with oral anticoagulants which, however, call for frequent laboratory controls, and with dextran which requires intravenous administration (Sevitt & Gallagher 1959 Borgstrom et al 1965, Harris et al 1967, Myhre & Holen 1969, Johnson et al 1968, Ahlberg et al 1968, Hamilton et al 1970)

Drugs that directly affect the platelet function have also been tried in order to diminish the frequency of thromboembolic episodes (O Brien et al 1971, Salzman et al 1971, Breddin & Scharrer 1972) In this way acetylsalicylic acid (ASA), a well-known inhibitor of platelet aggregation (O'Brien 1968, Zucker & Peterson 1968), has been tried with diverging results and since these have been inconclusive we have attempted to further elucidate its merits Acetylsalicylic acid was given in a double blind study and the incidence of postoperative thrombosis was evaluated using phlebographies

## MATERIAL AND METHODS

The study performed during 1971–1973 included 51 patients with severe osteoarthritis of the hip of whom 25 were female and 26 male Their ages varied between 43 and 78 years

The patients were operated on with displacement intertrochanteric osteotomy or with total hip arthroplasty (McKee Farrar) All but two of the osteotomies were performed by one surgeon (JS) using the same approach with division of vastus

lateralis postero laterally and cutting of the iliopsoas muscle at its insertion to the lesser trochanter All patients were kept in bed for one week, following which they were permitted partial weightbearing on crutches The total hip replacements were performed by the senior surgeons of the department, using either a lateral approach or the anterior (Smith Petersen) approach All patients with replacement were kept in bed for 8–10 days after which they were allowed partial weightbearing on crutches

Patients with previous thromboembolic diseases were excluded from the study All patients were carefully examined daily for clinical signs of deep venous thrombosis or pulmonary embolism postoperatively Fever, tachycardia, chest pains cough, tenderness of the calf, positive Homan's sign, and oedema were noted

No analgetics containing acetylsalicylic acid, phenylbutazone or indomethazon were given

The ascending phlebographies were performed in all patients 12 to 14 days postoperatively in the usual manner with the patients standing slightly recumbent to avoid layering phenomena" of the contrast medium in the bloodstream (Lindblom 1941 Greitz 1954) From 50 to 200 ml Urografin 45 per cent was injected into a superficial vein of the foot The examination in each case was, as a rule, performed with and without a tourniquet applied around the distal part of the lower leg just proximal to the ankle (The function of the tourniquet, as is well known, is to direct the contrast medium from the superficial veins into the deep venous system of the lower leg ) The flow of the contrast medium was followed on the TV-monitor and exposures were made mainly in the antero posterior and side projections

In a few cases in which an insufficient contrast filling of deep venous trunks made it difficult to distinguish a suspected thrombus from a possible free floating tail the examination was supplemented with a centripetal descending phlebography In this modification (*Bergvall 1971*) the patient lies supine and the leg to be examined is elevated approximately 30° or more The injection of contrast medium is made into a superficial foot vein and to prevent a quick passage of the contrast medium a tourniquet can be applied around the upper part of the thigh

In some cases where additional information about the iliofemoral segment was thought to be necessary a descending phlebography was also performed In these patients who as a rule were examined standing upright, the contrast medium was injected through a catheter inserted into the external iliac vein using the percutaneous approach

[illegible] ... to represent thrombi

Acetylsalicylic acid (ASA—Colfarit*) was given to 26 randomly selected patients and the remaining 25 patients were given placebo ASA as well as placebo were given in four daily doses of 0 5 g every 6 hours The randomization of the patients was performed in the following way The identical bottles containing acetylsalicylic acid and placebo pills respectively, were already on delivery to the hospital numbered and randomized by chance so that half of them contained ASA and the other half placebo Twenty per cent of the packages were marked at random with 1 indicating that platelet aggregation studies should be performed Every patient

* Colfarit and placebo were supplied by Bayer Pharmaceutical

on admission to the hospital received his own bottle from which the nurses distributed the medicine. Neither the patient, hospital staff nor the investigators were aware of the contents of the bottles until the code was broken at the end of the study by the Bayer Pharma. Treatment commenced on the first postoperative day and continued until phlebography had been performed 10–15 days postoperatively.

The level of salicylate in serum for all the patients was determined according to the method described by Saltzman** (1948). In the first 32 patients only one morning fasting sample was taken on the 5th, 6th or 7th day postoperatively. In the last 19 patients two samples for determination of the salicylate level were taken daily on the 2nd and on the 7th postoperative day at 7 a.m. fasting and at 2 p.m., i.e. 2 hours after they had taken the medicine.

Platelet aggregation was investigated in nine randomized patients according to the method described by Born & Cross (1963) on the 5th–7th postoperative days.

The statistical difference between the different groups was analyzed by the chisquare test with Yates' correction.

## RESULTS

Suspicion of a clinical deep venous thrombosis (DVT) arose in 11 of the 51 cases included in the study, i.e. 21 per cent. Of these 11 patients seven belonged to the group treated with ASA and four to the placebo group. In 35 of the 51 cases phlebography was successfully performed and interpreted. In the remaining 16 cases phlebography was not done because of refusal in six patients, technical difficulties in five patients and administrative problems in five patients. In one patient the phlebography was dubious and this patient was excluded.

Of the 35 patients on whom phlebography was successfully performed (only these patients will be discussed further), 15 were men and 20 women. Twenty-one were treated with ASA and fourteen were given the placebo. Nine had had a total hip replacement performed and 26 an osteotomy.

The total incidence of DVT verified by phlebography was 43 per cent, i.e. 15 patients out of 35 (Table 1), in comparison with the incidence found by clinical investigation which was 21 per cent, i.e. 11 patients out of 51.

However, the correlation between the clinical findings and the X-ray findings was not absolute. In 24 cases there was an agreement between the clinical and the X-ray findings, i.e. in 19 patients there was neither clinical nor radiological evidence of DVT, and the remaining five patients had positive phlebographies with positive clinical signs. In 11

**) Determination of salicylates in serum was kindly performed by Dr. Ann Catrine Teger-Nilsson, Clinical Chemistry Laboratory, Karolinska Hospital.

*Table 1* Number of patients and incidence of DVT

| Patients | Clinical investigation | Phlebographical investigation |
|---|---|---|
| Total no of patients investigated | 51 | 35 |
| No of patients with signs of DVT | 11 (21 %) | 15 (43 %) |

patients, however, there was a discrepancy between the clinical and the X-ray findings In 10 of these patients there was no clinical suspicion of DVT but phlebography indicated thrombosis, and in one case the clinical investigation raised a suspicion of DVT but the X-ray was normal (Table 2)

In the group treated with placebo the incidence of DVT was 36 per cent (five out of 14 patients), and in the ASA treated group it was 47 per cent (10 out of 21 patients), which yields no statistically significant difference between the groups (Table 3) The incidence of DVT with respect to age, sex and type of operation is shown in Table 4

Estimation of the salicylate concentration in serum was made once in the first 32 patients investigated Samples were drawn in the morning about 6–8 hours after the last medication Of those treated with ASA, the salicylate-concentrations varied between 0 4 and 9 5 mg per cent In the last 19 patients investigated four samples were drawn, two as a morning sample and two in the afternoon about 2 hours after medication The concentration of salicylates in the ASA-treated group varied between 0 8 and 22 mg per cent where the noon samples exceeded the morning samples by 1 2–6 mg per cent

To evaluate if the incidence of DVT was dependent on the salicylate concentration the salicylate group was divided into two groups, one with the lowest determined salicylate concentration below 2 mg per

*Table 2* Number of patients with and without signs of DVT in the clinically and phlebographically investigated patients respectively

| Clinical judgement | Phlebography | | | |
|---|---|---|---|---|
| | DVT | Non DVT | Not performed | Total no |
| DVT | 5 | 1 | 5 | 11 |
| Non DVT | 10 | 19 | 11 | 40 |
| Total no | 15 | 20 | 16 | 51 |

on admission to the hospital received his own bottle from which the nurses distributed the medicine Neither the patient, hospital staff nor the investigators were aware of the contents of the bottles until the code was broken at the end of the study by the Bayer Pharma Treatment commenced on the first postoperative day and continued until phlebography had been performed 10-15 days post operatively

The level of salicylate in serum for all the patients was determined according to the method described by Saltzman** (1948) In the first 32 patients only one morning fasting sample was taken on the 5th 6th or 7th day post operatively In the last 19 patients two samples for determination of the salicylate level were taken daily on the 2nd and on the 7th postoperative day at 7 a m fasting and at 2 p m, i e 2 hours after they had taken the medicine

Platelet aggregation was investigated in nine randomized patients according to the method described by Born & Cross (1963) on the 5th–7th postoperative days

The statistical difference between the different groups was analyzed by the *chisquare test with Yates' correction*

## RESULTS

Suspicion of a clinical deep venous thrombosis (DVT) arose in 11 of the 51 cases included in the study, i e 21 per cent Of these 11 patients seven belonged to the group treated with ASA and four to the placebo group In 35 of the 51 cases phlebography was successfully performed and interpreted In the remaining 16 cases phlebography was not done because of refusal in six patients, technical difficulties in five patients and administrative problems in five patients In one patient the phlebography was dubious and this patient was excluded

Of the 35 patients on whom phlebography was successfully performed (only these patients will be discussed further), 15 were men and 20 women Twenty-one were treated with ASA and fourteen were given the placebo Nine had had a total hip replacement performed and *26 an osteotomy*

The total incidence of DVT verified by phlebography was 43 per cent i e 15 patients out of 35 (Table 1), in comparison with the incidence found by clinical investigation which was 21 per cent, i e 11 patients out of 51

However, the correlation between the clinical findings and the X ray findings was not absolute In 24 cases there was an agreement between the clinical and the X-ray findings, i e in 19 patients there was neither clinical nor radiological evidence of DVT, and the remaining five patients had positive phlebographies with positive clinical signs In 11

**) Determination of salicylates in serum was kindly performed by Dr Ann Catrine Teger Nilsson Clinical Chemistry Laboratory Karolinska Hospital

*Table 5.* Total number of patients treated with placebo and ASA, respectively, and incidence of DVT. The ASA treated group is divided into those with the lowest observed salicylate concentration above and below 2 mg per cent, respectively

| Subgroups | | Placebo | | ASA lowest conc. above 2 mg % | | ASA lowest conc. below 2 mg % | |
|---|---|---|---|---|---|---|---|
| | | Total no | DVT Total no (%) | Total no | DVT Total no (%) | Total no | DVT Total no (%) |
| Ages | 40–55 | 2 | 0 (—) | 2 | 1 (50) | 3 | 2 (66) |
| | 56–65 | 7 | 2 (29) | 2 | 0 (—) | 6 | 3 (50) |
| | 66–80 | 5 | 3 (60) | 7 | 4 (57) | 1 | 0 (—) |
| Sexes | Female | 6 | 2 (33) | 9 | 5 (55) | 5 | 3 (60) |
| | Male | 8 | 3 (37) | 3 | 0 (—) | 5 | 2 (40) |
| Type of operation | Total hip | 3 | 1 (33) | 4 | 2 (50) | 2 | 1 (50) |
| | Osteotomy | 11 | 4 (36) | 7 | 3 (43) | 8 | 4 (50) |

*Table 3 Number of patients with and without phlebographically verified DVT in the ASA- and placebo treated patients, respectively Chi$_y^2$ (with Yates correction) = 0 30 (non significant)*

| Treatment | Diagnosis | | Total no |
|---|---|---|---|
| | DVT | Non DVT | |
| ASA | 10 | 11 | 21 |
| Placebo | 5 | 9 | 14 |
| Total no | 15 | 20 | 35 |

cent and the other with the lowest determined salicylate concentration above 2 mg per cent When these groups were compared with the placebo-treated group almost the same incidence of DVT was found in all three groups (Table 5)

The platelet aggregation test was performed to verify if ASA would alter platelet aggregation This test was performed once in nine patients Four of these were treated with placebo, only one showed an inhibited platelet aggregation induced by collagen, whereas the other three had a normal aggregation None of these four patients had any measurable amounts of salicylate in serum The other five patients belonged to the ASA-treated group Four of these had an inhibited platelet aggregation and in one the aggregation curves were not reliable None of these patients had an observed salicylate concentration below 1 4 mg per cent

*Table 4 Total number of ASA- and placebo treated patients, respectively and total number (and per cent) of patients with phlebographically verified DVT in the different groups*

| Subgroups | | ASA | | Placebo | |
|---|---|---|---|---|---|
| | | Total no | DVT No (%) | Total no | DVT No (%) |
| Ages | 40–50 | [illegible] | 3 (60) | 2 | 0 (—) |
| | 56–65 | 9 | 3 (33) | 7 | 2 (29) |
| | 66–80 | 7 | 4 (57) | 5 | 3 (60) |
| Sexes | Female | 14 | 8 (57) | 6 | 2 (33) |
| | Male | 7 | [illegible] (29) | 8 | 3 (37) |
| Type of operation | Total hip | 6 | 3 (50) | 3 | 1 (33) |
| | Osteotomy | 15 | 7 (47) | 11 | 4 (36) |

veins of varying severity (factors predisposing to venous stasis and increased risk for development of thrombi) there will not only be progress in thrombi formed during the operation but probably also formation of new thrombi will take place postoperatively (Culver et al 1970) Thus, we assumed that if ASA had any significant effect in abolishing DVT this would take place also if the treatment were started on the first postoperative day Furthermore, if it were documented that ASA could prevent thrombus formation when administered post operatively, it would also be of benefit to patients with traumatic injuries

The platelet aggregation performed with collagen was inhibited in those patients treated with ASA One patient in the placebo group had an inhibited collagen induced platelet aggregation without any detectable amounts of salicylates in serum and it was assumed that the effect of some drug taken prior to admission to hospital was still detectable in the aggregation test of this patient

In spite of the altered platelet function and irrespective of the salicylate concentration in serum our results do not show any altered incidence of DVT after hip surgery in patients treated with 2 g ASA daily, administered from the first postoperative day

## SUMMARY

Fifty one patients were investigated concerning thromboembolic complications in the operated leg after elective surgery of the hip Suspicion of clinical deep venous thrombosis (DVT) arose in 11 patients, i e 21 per cent Thirty-five patients were investigated with phlebography The incidence of DVT among those patients was 15 cases, i e 43 per cent

It is concluded that acetylsalicylic acid, a drug which inhibits the platelet release reaction and thereby blocks the platelet aggregation, given orally in a dose of 2 gram per day from the first postoperative day is not effective in diminishing the incidence of postoperative deep venous thrombosis

## ACKNOWLEDGEMENTS

We express our sincere gratitude to Dr Margareta Blombäck for valuable support and discussions This work was supported by grants from the Swedish Medical Research Council (19X 520) and from Lila and Gustaf af Ugglas foundation

No side effects after ASA in the form of anaphylaxis or increased bleeding were noticed, but because of gastrointestinal disturbances in five patients the treatment had to be stopped These patients were then excluded from the study, and are not included with the 51 patients

## DISCUSSION

The reported incidence of deep venous thrombosis (DVT) following hip surgery, documented in various publications (Hamilton et al 1970, Bergquist et al 1972), varies between 30 and 50 per cent These results are in accordance with our findings, i e 43 per cent

Agents directly affecting the platelet function, i e acetylsalicylic acid that inhibits the platelet release reaction and thus interferes with the platelet aggregation, have also been used in trials to prevent thromboembolic diseases, and it is reasoned that if the initial platelet thrombosis can be avoided the subsequent development of a fibrin clot might be prevented

Probably this kind of drug would be of more value in preventing arterial thrombi, due to their relatively larger number of aggregated platelets, but ASA has been tried with diverging results as a prophylaxis against venous thrombosis O'Brien et al (1971) reported no decrease in postoperative thrombosis detected with $I^{125}$-labelled fibrinogen in patients treated with ASA compared with placebo, they used ASA in two doses, 0 6 and 2 4 g/day, respectively On the other hand, Salzman et al (1971) suggested a positive effect regarding clinically diagnosed thrombosis after postoperative treatment with 1 2 g ASA/day with patients on whom elective arthroplasty of the hip had been performed Their data suggested ASA to be as effective as dextran and warfarin but they advised further examination before ASA could be considered as a drug of choice Furthermore, Breddin & Scharrer (1972) reported a decrease in clinically diagnosed thromboembolic episodes postoperatively in patients treated with ASA, 1 5 g daily, compared with patients given placebo

We are aware that criticism can be raised against our starting with ASA the first postoperative day, when a thrombosis might have already been formed during the operation and it would thus be too late to achieve any effective prophylaxis

However, in elderly patients, with more or less pronounced arteriosclerosis, and varying degrees of congestive heart failure and varicose

veins of varying severity (factors predisposing to venous stasis and increased risk for development of thrombi) there will not only be progress in thrombi formed during the operation but probably also formation of new thrombi will take place postoperatively (Culver et al 1970) Thus we assumed that if ASA had any significant effect in abolishing DVT this would take place also if the treatment were started on the first postoperative day Furthermore if it were documented that ASA could prevent thrombus formation when administered post operatively it would also be of benefit to patients with traumatic injuries

The platelet aggregation performed with collagen was inhibited in those patients treated with ASA One patient in the placebo group had an inhibited collagen induced platelet aggregation without any detectable amounts of salicylates in serum and it was assumed that the effect of some drug taken prior to admission to hospital was still detectable in the aggregation test of this patient

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Fifty-one patients were investigated concerning thromboembolic complications in the operated leg after elective surgery of the hip Suspicion of clinical deep venous thrombosis (DVT) arose in 11 patients i e 21 per cent Thirty five patients were investigated with phlebography The incidence of DVT among those patients was 15 cases i e 43 per cent

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*Key words* acetylsalicylic acid, thromboembolism, hip surgery, osteoarthritis

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Acta orthop scand 46 256-268, 1975

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# BONE DEFORMATION RECORDED IN VIVO FROM STRAIN GAUGES ATTACHED TO THE HUMAN TIBIAL SHAFT

L E Lanyon, W G J Hampson, A E Goodship & J S Shah

Accepted 5 ix 74

It is generally accepted that mechanical circumstances can profoundly influence the course of growth, remodelling and repair in bone How this influence exerts itself is obscure and is unlikely to be clarified until more is known of the mechanical circumstances involved A knowledge of these circumstances also becomes increasingly important as greater emphasis is placed on the internal fixation and prosthetic replacement of skeletal components

Instrumentation of a bone's surface with strain gauges has made it possible to record bone deformation during various activities in animals (Lanyon & Smith 1970, Lanyon 1973, 1974) Such data are of limited significance being relevant only to a small area of the bone surface However this method is the only one at present available which has produced direct information on how a bone responds to normal loading The value of such information is to some extent determined by whether generalisations concerning this skeletal response in one species are applicable to others, in particular to man In an attempt to determine the relevance of animal data to man it was decided to instrument part of the human skeleton using the techniques previously employed on experimental animals The antero-medial aspect of the tibial midshaft was chosen for its surgical accessibility

## MATERIALS AND METHODS

A foil 45° rosette strain gauge was attached to the anteromedial aspect of the tibial midshaft of a 35 year old normal active man 1 7 m in height, weighing 66 kg (W G J H ) The gauge was prepared in a similar way to those used in the animal experiments previously mentioned

The tissues overlying the proposed gauge site were infiltrated with local anaesthetic solution and an incision [illegible] cm long made down to the periosteum. A 15 mm square was removed from the periosteum, haemostasis was obtained and the back of the gauge flooded with adhesive (isobutyl 2-cyanoacrylate monomer) before being pressed into position on the bone surface. The wires leading from the gauge were sutured to the periosteum and the wound closed leaving them to emerge from the proximal end of the incision. Within an hour of the operation the subject was walking and running on a moving belt machine. Recordings were then taken at this time and on the two subsequent days. On the third day the wound was reopened and the gauge removed.

The gauge recordings were actually a display of the change in resistance of the three separate elements of the rosette. These were interpreted in terms of strain by using the known relationship between change in the length of the gauge and change in its resistance (Gauge Factor). An indication of zero strain was obtained by recording the strain level when the limb was bearing no weight. This approximated to the level indicated during the period of slow strain change when the limb was in mid swing (Figure 1). However, as the final positioning of the

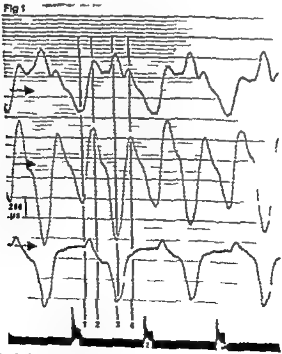


*Figure 1 Part of the recording taken soon after the operation during walking at 1.5 m/s on the belt wearing shoes. The traces from the three gauges are shown, the zeros are arrowed. Points 1–4 correspond to those in Table 1 and in the analysis Figure 2*

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*...he principal tension ($E_1$) expressed in microstrain and the angle of the principal ... onsecutive strides for the activities described at the points illustrated (1–4 Figure ... tride is given in microstrain per second the asterisk indicates to which peak strain ... axis is given proximal to the gauge postero medial positive antero lateral negative*

| 2 Full foot heel off | | | 3 Heel off toe off | | | 4 Forward swing | | |
|---|---|---|---|---|---|---|---|---|
| $E_1$ | $E_2$ | $\theta_1$ | $E_1$ | $E_2$ | $\theta_1$ | $E_1$ | $E_2$ | $\theta_1$ |
| 254 | −140 | −3 | 395 | −434* | −53 | 35 | −34 | +4 |
| ± 40 | ± 18 | ± 3 | ± 76 | ± 28 | ± 1 | ± 7 | ± 5 | ± 3 |
| 210 | −104 | +11 | 311 | −368* | −54 | 171 | −[illegible] | +[illegible] |
| ± 54 | ± 20 | ± 3 | ± 40 | ± 44 | ± 1 | ± 7 | ± 6 | ± 1 |
| 129 | −82 | +20 | 237 | −308* | −52 | 92 | −67 | +9 |
| ± 12 | ± 14 | ± 1.5 | ± 18 | ± 21 | ± 1 | ± 7 | ± 11 | ± 0.5 |
| 185 | 106 | +16.5 | 328 | −393* | −51 | 137 | −104 | +15 |
| ± [illegible] | ± 21 | ± 2.5 | ± 22 | ± 26 | ± 1 | ± 23 | ± 29 | ± 1 |
| 241 | −131 | +13 | 366 | −412* | −50 | 162 | −96 | +11 |
| ± 27 | ± 21 | ± 2 | ± 81 | ± 98 | ± 1.5 | ± 21 | ± 13 | ± 1 |
| 387 | −224 | +12 | 341 | −425 | −49 | 196 | −113 | +13.5 |
| 43 | ± 36 | ± 1.5 | ± 51 | ± 57 | ± 1.5 | ± 18 | ± 14 | ± 1 |
| 2 Toe strike toe off | | | | | | | | |
| 847 | 578 | −4 | | | | | | |
| [illegible] | ± 31 | ± 3 | | | | | | |
| 746* | −450 | −5 | | | | | | |
| ± 64 | ± 37 | ± 3 | | | | | | |

## RESULTS

The results presented concern the strain gauge recordings taken during the subject's locomotion both on the moving belt and on the floor The traces illustrated in Figure 1 were obtained while he was walking on the belt within an hour of the operation The analysis of such traces (Figures 2 and 3) shows the changing principal strains and strain angle during typical strides walking on the belt with and without shoes The strain angle illustrated is that of the principal tension relative to the tibia's long axis proximal to the gauge The postero-medial direction is expressed as positive and the antero lateral direction as negative By definition the principal compression acts at 90° to the principal tension at all times

The overall pattern of deformation change during a walking stride appeared to occur in four definite phases Two of these were during the

*Table 1 The mean and standard deviations of the principal compression ($E_2$) an... tension to the tibia's long axis ($\Theta_1$) in degrees calculated for a number ... 1 1 and 2 Figure 1) The maximum strain rate encountered during th s typ... value it refers Tension is expressed positive compression negative the angle to the lo...*

| | Max strain rate | $E_1$ | 1 Heel strike E | $\theta_1$ |
|---|---|---|---|---|
| Day 1 Belt walk no shoes at 1 4 m/s<br>Stride duration 0 97 ± 01 s | $-4 \times 10^{3*}$ | 73<br>± 5 | —154<br>± 7 | —[illegible]<br>+ 1 |
| Day 1 Belt walk with shoes at 1 5 m/s<br>Stride duration 0 99 ± 01 s | $-3\ 37 \times 10^{3*}$ | 98<br>± 5 | —178<br>± 6 | —[illegible]<br>+ 1 |
| Day 2 Floor walk with shoes no load<br>Stride duration 1 08 ± 02 s | $-2\ 3 \times 10^{3*}$ | 64<br>± [illegible] | —113<br>± 6 | —[illegible]<br>+ [illegible] |
| Day 2 Floor walk with shoes and 27 kg<br>Stride duration 1 03 ± 01 s | $-2\ 15 \times 10^{3*}$ | 58<br>± 11 | —113<br>± 6 | —[illegible]<br>+ 2 |
| Day 2 Floor walk with shoes and 45 kg<br>Stride duration 1 10 ± 01 s | $-2\ 7 \times 10^{3*}$ | 43<br>± 4 | —109<br>± 7 | —[illegible]<br>+ 1 |
| Day 2 Floor walk with shoes and 71 kg<br>Stride duration 1 10 ± 01 s | $+4\ 2 \times 10^{3*}$ | 41<br>± 10 | — 89<br>± 6 | —[illegible]<br>± 1 |
| | | | 1 Toe strike | |
| Day 1 Belt run no shoes at 2 2 m/s<br>Stride duration 0 73 ± 02 s | $+11\ 75 \times 10^{3}$ | 124<br>± 12 | —290<br>± 18 | —83<br>± 1 |
| Day 2 Belt run with shoes at 2 2 m/s<br>Stride duration 0 69 ± 01 s | $+13 \times 10^{3*}$ | 177<br>± 11 | —300<br>± 13 | —84<br>± 1 |

zero line was subject to some error indications of strain and strain angle at or near zero should be treated with suspicion

The traces recorded during repetitive activities such as walking were treated as follows using the estimated zero strain the strain level on all three gauges was measured at the four distinct inflections (1–4 Figure 1) for 10 consecutive cycles while walking on the belt or for five consecutive cycles walking on the floor By using standard formulae (Dally & Reilly 1965) the principal strains and principal angles were calculated for these positions (Table 1) A typical cycle was then chosen whose parameters fell as near as possible within one standard deviation of the mean for that recording The strain levels during this cycle were measured and calculated for every 0 02 second interval (Figures 2 7)

Correlation of the subject's position and the gauge recordings was made possible by filming at 64 frames per second (Figure 5 a)

*ıe principal tension ($E_1$) expressed in microstrain, and the angle of the principal*
*ɔnsecutive strides for the activities described at the points illustrated (1–4, Figure*
*tride is given in microstrain per second, the asterisk indicates to which peak strain*
*xis is given proximal to the gauge, postero medial positive, antero lateral negative*

| [illegible] Full foot heel off | | | 3 Heel off toe off | | | 4 Forward swing | | |
|---|---|---|---|---|---|---|---|---|
| $E_1$ | $E_2$ | $\theta_1$ | $E_1$ | $E_2$ | $\theta_1$ | $E_1$ | $E_2$ | $\theta_1$ |
| 254 ± 40 | —140 ± [illegible] | — 3 ± 3 | 395 ± 76 | —434* ± 28 | —53 ± 1 | 35 ± 7 | — 34 ± 5 | + 4 ± 3 |
| 210 ± 54 | —104 ± 20 | +11 ± 3 | 311 ± 40 | —368* ± 44 | —54 ± 1 | 171 ± 7 | — 98 ± 6 | + 6 ± 1 |
| 128 ± 12 | — 82 ± 14 | +20 ± 1 5 | 237 ± 18 | —308* ± 21 | —52 ± 1 | [illegible] ± 7 | — 67 ± 11 | + 9 ± 0 5 |
| 185 ± 44 | —106 ± 21 | +16 5 ± 2 5 | 328 ± 22 | —393* ± 26 | —51 ± 1 | 137 ± 23 | —104 ± 29 | +15 ± 1 |
| 241 + 27 | —131 ± 41 | +13 ± 2 | 366 ± 81 | —412* ± 98 | —50 ± 1.5 | 162 ± 21 | — 96 ± 13 | +11 ± 1 |
| 397* + 49 | 224 ± 36 | +12 ± 1 5 | 341 ± 51 | —425 ± 57 | —49 ± 1 5 | 196 ± 18 | —113 ± 14 | +13 5 ± 1 |
| 2 Toe strike toe off | | | | | | | | |
| 847* 59 | 578 ± 31 | — 4 ± 3 | | | | | | |
| 746* + 64 | 430 ± 37 | — 5 ± 3 | | | | | | |

## RESULTS

The results presented concern the strain gauge recordings taken during the subject's locomotion both on the moving belt and on the floor The traces illustrated in Figure 1 were obtained while he was walking on the belt within an hour of the operation The analysis of such traces (Figures 2 and 3) shows the changing principal strains and strain angle during typical strides walking on the belt with and without shoes The strain angle illustrated is that of the principal tension relative to the tibia's long axis proximal to the gauge The postero-medial direction is expressed as positive and the antero-lateral direction as negative By definition the principal compression acts at 90° to the principal tension at all times

The overall pattern of deformation change during a walking stride appeared to occur in four definite phases Two of these were during the

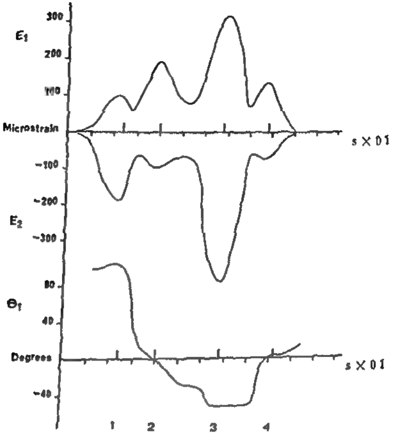


*Figure 2. Analysis of the recordings in Figure 1 to show the changing principal strains $E_1$ and $E_2$, and the angle of the principal tension to the bone's long axis (strain angle, $\theta_t$) during one stride. The points 1–4 correspond to those in Figure 1*

limb's swing period, one at the end, prior to 'heel strike', and one at the beginning as the limb was swung forward. During the one prior to 'heel strike' the principal compression was larger than the principal tension and practically in line with the long axis (Table 1). During the swing forward this was reversed. The remaining two deformation phases occurred during the stance period of the limb. The first was between 'full foot' and 'heel off', during which time when walking on the belt the direction of the principal tension crossed that of the bone's long axis. The second was between 'heel off' and 'toe off' when the angle of the principal tension to the long axis remained a constant −53 to −54 degrees.

The wearing of shoes made the deformation cycles more definite and discrete. The amount of deformation was increased during the swing period phases and decreased during those when the foot was on the ground.

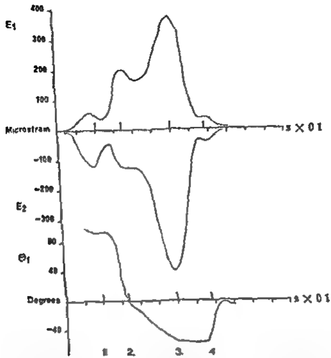


*Figure 3 Analysis to show the changing principal strains and strain angle during one stride walking on the belt without shoes at 1.4 m/s soon after the operation The points 1–4 correspond to those in Table 1 and Figures 1 and 2*

Table 1 shows the principal strains and the strain angle calculated for the four distinct inflexions illustrated on the original gauge traces (Figure 1, 1–4) These coincided approximately with the principal strain peaks The maximum strain rate given was the maximum increase per second which occurred in either principal strain at a constant angle during the typical stride of that particular recording

In addition to walking on the moving belt the subject walked on the concrete floor with and without a rucksack containing various loads Figure 5 a shows the analysis of a stride taken on the floor, wearing shoes but carrying no load The strain change pattern differed from those obtained on the belt in that the strain angle between 'full foot' and heel off' remained more constant This seemed to be a real difference between walking on the floor and on the belt, it was not related to the speed of walking nor in subsequent cine film analysis

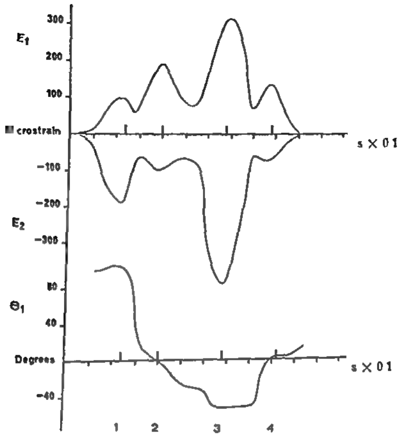


*Figure 2 Analysis of the recordings in Figure 1 to show the changing principal strains $E_1$ and $E_2$ and the angle of the principal tension to the bone's long axis (strain angle $\Theta_1$) during one stride The points 1–4 correspond to those in Figure 1*

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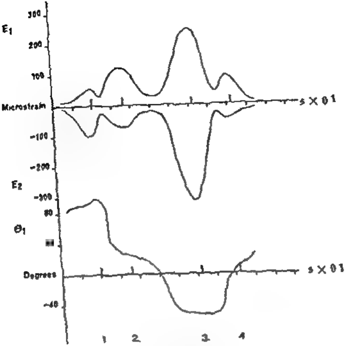


*Figure 51 Analysis to show the changing principal strains and strain angle during a single stride while walking on the floor the day after the operation wearing shoes but carrying no load*

toe strike' and 'toe off' At this time the principal tension, which was the larger principal strain, was aligned along the bone's long axis

Recordings were taken during these and other activities over a period of three days Qualitatively there was no change in deformation pattern over this time The amount of deformation however was less by about 25 per cent on the second and third days than on the first

## DISCUSSION

At best the results presented relate solely to the strain at the surface of a small area of the tibia in one individual In addition although the directional and comparative data should be valid the quantitative data have not been substantiated in absolute terms We have assumed that the changes in dimensions of the gauge reflected those which occurred in the bone beneath it Although this is standard engineering procedure the bonding of strain gauges is usually done under more favourable

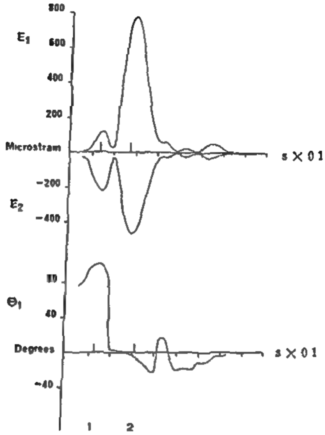


*Figure 4 Analysis to show the changing principal strains and strain angle during one stride running on the belt without shoes at 2 2 m/s soon after the operation The points 1 and 2 correspond to those in Table 1*

have we been able to observe any gross difference in the positioning of the leg during a stride on a moving and non-moving surface

Figures 6 and 7 show the analyses of strides taken while walking on the floor under increasing loads The angle change pattern remained practically the same, the amount of deformation increased especially during the stance periods The greater increase occurred during the mid stance phase between 'full foot' and 'heel off' Under a load of 70 kg, this became larger than the 'toe push' phase

It was not possible to run on the floor with trailing wires so this was done only on the moving belt Figure 4 shows the analysis of a stride taken during such a run without shoes Only two deformation cycles of any size occurred One of these was at the end of the swing phase prior to 'toe strike' and differed little from that which in the walks occurred prior to 'heel strike' The other, during the stance phase was much larger, the deformation reached a maximum mid-way between

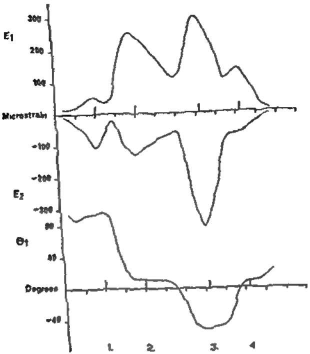


*Figure 6 The analysis of a single stride while walking on the floor wearing shoes and carrying 27 kg Points 1–4 correspond to those in Table 1 and Figures 1 5*

allowing the subject a lengthy period of locomotion at a variety of speeds while still connected by wires to the recording apparatus However, although no obvious difference in gait was detectable from the films of the subject walking on a moving or a non moving surface, there was a consistent difference between the two in the strain angle change during the mid stance period No comparison was possible between running on the belt and the floor, however, alterations in the movement of the centre of gravity such as those reported by Nelson et al (1972) would probably be reflected in differences in the mechanical circumstances of the limbs In these respects at least, conveyor belt walking must be considered abnormal

The reduction in amount of deformation over the three days of the experimental period is unexplained Possibly the bone gauge bond was weakening, although there were no obvious signs that it had done so when the gauge was removed Possibly also on the first day, with the operation site still partially anaesthetised, the subject's walking was

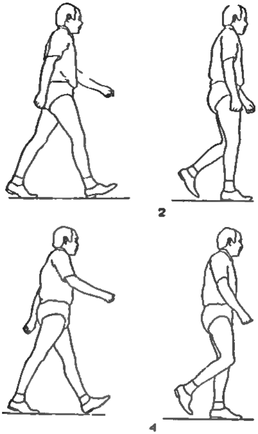


*Figure 5ii The man's position as taken from cine film at the points 1–4 in Figure 5i These correspond to those in Table 1 and Figures 1–3*

conditions than those existing *in vivo* In our previous experiments the most common results of faulty technique have been defective bonds between gauge and bone and/or pulling on the lead wires Both of these give misleading recordings but it has usually proved possible to detect the difference between the aberrant results produced under these conditions and those obtained from a gauge which is satisfactorily attached In this experiment there were no grounds for suspecting any such unreliability in the recordings Working on the assumption that they were reliable and considering the extent of the surgical interference necessary for the experiment it was not considered justifiable to repeat it for the sake of duplicate results Our intention was not to investigate the human tibia *per se* but only to establish whether generalisations concerning the loading conditions of bone in other species were at variance with those in man

Moving belt walking has the great experimental advantage of

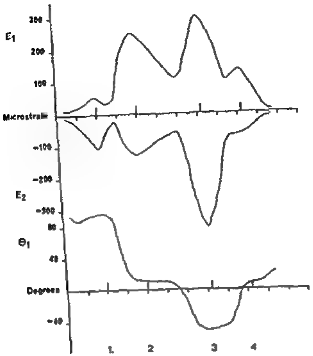


*Figure 6 The analysis of a single stride while walking on the floor wearing shoes and carrying 27 kg Points 1–4 correspond to those in Table 1 and Figures 1–5*

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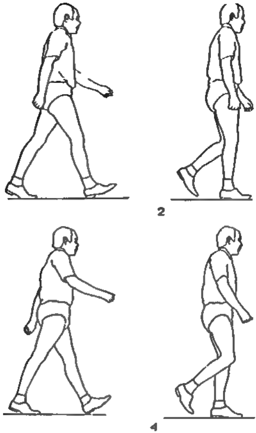

1 2 3 4

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deformation phase there was an alteration in the strength and direction of muscle pull at least as fast as that in tibial alignment. Between phases this alteration was much faster.

The existence of a series of definite angles at which any particular piece of bone is customarily deformed has some experimental implications. If in the laboratory it is required to reproduce physiological loading of skeletal fragments there are certain directions in which this should be done which do not necessarily coincide with the bone's overall axis or that of its tissue. However if the customary strain direction in cortical bone does have some orienting effect on bone architecture the tissue direction should bear some consistent relationship to it. Unfortunately little is known at present of the mechanisms by which continued intermittent deformation influences bone structure and so the relative importance of large or small deformation cycles and the significance of their alignment is at present speculative. Except for knowing that mechanical conditions are 'important' we know nothing of which aspect of them is relevant and how it acts.

The amounts of deformation and the strain rates encountered in this experiment are directly comparable to those in similar experiments on animals. The deformation phases with constant loading directions are another feature common to both. It is probable that any information obtained in such experiments on animals will have a common significance to man.

## SUMMARY

A strain gauge rosette was attached to the midshaft of a man's tibia. This demonstrated that during every stride the bone surface was subjected to a number of discrete deformation cycles. During each cycle the bone was deformed from a particular direction, released at least partially and then deformed from another direction.

This feature has been observed from a number of sites in experimental animals.

The largest deformation occurred while the subject was running, the principal tension then reached 850 microstrain applied in line with the bone's long axis at $13 \times 10^3$ microstrain per second. When walking the largest deformation occurred prior to 'toe off', compression was then the larger principal strain about $-400$ microstrain applied at 37° to the bone's long axis at $-4 \times 10^3$ microstrain per second. These strain values are the same order of size as those recorded from the long bones of sheep and pigs during their locomotion.

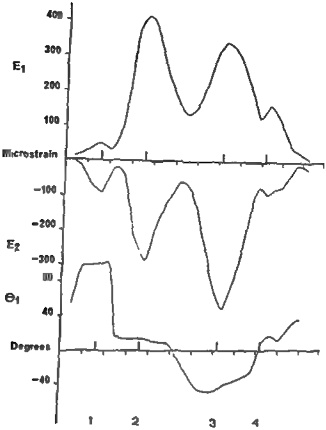


*Figure 7 The analysis of a single stride while walking on the floor wearing shoes and carrying 71 1g Points 1–4 correspond to those in Table 1 and Figures 1–6*

more definite than on the subsequent days when more reaction was present

The differences between wearing and not wearing shoes were distinct and constant Presumably their extra weight on the end of the limb could contribute to the increased deformation recorded during the swing period, and their cushioning effect to the decrease during the stance period

Of greater significance than these variations is the fact that each stride was not characterised by a gradual progression or continuum of loading conditions but rather it consisted of a series of discrete events during each of which the bone was deformed from a particular direction, released at least partially, and then loaded from another direction

The deformation was presumably the result of the combined effects of muscle pull and body weight However the tibia's orientation with respect to gravity was under continual change throughout the stride while the strain direction was not This implies that during each

deformation phase there was an alteration in the strength and direction of muscle pull at least as fast as that in tibial alignment Between phases this alteration was much faster

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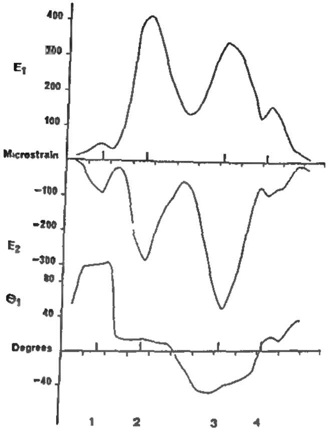


*Figure 7 The analysis of a single stride while walking on the floor, wearing shoes and carrying 71 kg Points 1–4 correspond to those in Table 1 and Figures 1–6*

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Acta orthop scand 46, 269 279, 1975

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# TISSUE OXYGEN AND CARBON DIOXIDE TENSIONS IN HEALING RABBIT TIBIAS

JAAKKO KIVISAARI & JUHA NIINIKOSKI

Accepted 15.x 74

Recent studies have demonstrated that tissue gas tensions can be measured by implanting a Silastic tube into the target organ (Niinikoski & Hunt 1972, Kivisaari & Niinikoski 1973) Silastic is highly permeable to respiratory gases and, therefore, the fluid filling the tube quickly equilibrates to the average $PO_2$ and $PCO_2$ of the surrounding tissue

This paper reports determinations of tissue oxygen and carbon dioxide tensions in healing rabbit tibias with the above method Baseline tissue gas tensions and the response to systemic hyperoxia and hypercarbia were recorded Additionally, response of bone $PO_2$ and $PCO_2$ to occlusion of local circulation was determined, and bone $PCO_2$ was recorded after intravenous administration of acetazolamide, an inhibitor of carbonic anhydrase

## MATERIAL AND METHODS

Oxygen and carbon dioxide tensions of healing bones were measured by the method originally developed for the determination of $PO_2$ and $PCO_2$ in soft tissue wounds (Kivisaari & Niinikoski 1973) The tonometer was made from a gas permeable, barium impregnated x ray positive Silastic tube 17 cm long, with an outside diameter of 1 5 mm and an inside diameter of 1 1 mm The tubing is commercially available in sterile packings and is commonly used in ventriculoatriostomies for the treatment of hydrocephalus *

Twelve white male rabbits weighing 2.5–3.5 [illegible] animals [illegible] The left [illegible] Through

This work was supported in part by Contract No. [illegible] ...e U S Army [illegible]

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ACKNOWLEDGEMENTS

We should like to thank Mr P G Stableforth for his part in performing the operation

The technical staff in the Department of Veterinary Anatomy under Mr M A Coombs assisted greatly throughout the experiment Filming and photography was by Mr D Telling and illustrations by Mr T Wiltshire

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*Key words* bone, biomechanics strain gauges, tibia human, *in vivo*

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by filling the tonometer with another dose of hypoxic saline from 1 ml syringe The capillary was mounted into a micro sample injector* and the sample was emptied into a thermostated cuvette containing either an $O_2$ or $CO_2$ electrode The electrodes were connected with a gas monitor PHM 71 *

Zero adjustment of the $O_2$ electrode was obtained with gaseous nitrogen and calibration took place with aerated saline $PO_2$ 150 mmHg using the capillary sampling technique The $CO_2$ electrode was also calibrated by the capillary sampling technique using saline solutions of two known $CO_2$ tensions (26 and 63 mmHg)

After induction of the anesthesia baseline tissue gas tensions in the healing tibias were determined The responses of tissue $PO_2$ and $PCO_2$ to breathing of a gas mixture containing 95 per cent $O_2$ and 5 per cent $CO_2$ were then recorded The gas mixture was supplied by means of a head tent and the $O_2$ and $CO_2$ concentrations inside the tent were checked with a gas analyzer In some animals the blood flow to the limb was hindered by a tight tourniquet to see the effect of vascular occlusion on tissue gas tensions Response of bone tissue gases to the release of circulation was also recorded In six animals bone $PCO_2$ was recorded after a single intravenous injection of acetazolamide** an inhibitor of carbonic anhydrase (Minkin & Jennings 1972) In each animal acid base equilibrium and oxygen and carbon dioxide tensions of the arterial blood were determined at short intervals in samples taken from the ear artery

After the measurements were completed the rabbits were sacrificed and the bones with the implanted Silastic tubes were removed for histologic study The samples were fixed decalcified and sections stained with hematoxylin and eosin

## EXPERIMENTAL RESULTS

A rapid decline in the baseline bone PO from 32 to 25 mmHg occurred within the first three days postimplantation (Figure 2) During the following 52 days the $PO_2$ rose gradually to 42 mmHg The maximum $PO_2$ in the healing tibia during breathing of 95 per cent $O_2$ and 5 per cent $CO_2$ rose progressively from the first day value of 35 mmHg to a level of 140 mmHg by the 30th day Thereafter, no further increase was noted in the response to systemic hyperoxia

The baseline $PCO_2$ in the healing tibia rose from 61 mmHg on the first day to 85 mmHg on day 3 (Figure 3) Thereafter, the $PCO_2$ gradually declined to 57 mmHg by the 30th day, a level which was maintained until the end of the observation period The maximum PCO during breathing of 95 per cent O and 5 per cent $CO_2$ increased from 65 to 101 mmHg during the first three days after implantation and then decreased to a level of 65 mmHg by the 30th day

Occlusion of the circulation to the leg by means of a tourniquet

* Radiometer Copenhagen Denmark
** Diamox® Lederle U S A

SILASTIC TONOMETER IN RABBIT TIBIA

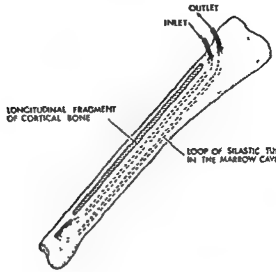


*Figure 1. The experimental design for measuring tissue gas tensions in the rabbit tibia injured by implantation of the Silastic tube.*

a medial incision, periosteum was split and the surface of the cortex was exposed A longitudinal fragment of cortex was cut out with a dental drill with a fissured taper The medulla was removed as completely as possible and stored under sterile conditions The inner surface of the cortex was then abraded with the drill to ensure a circumferential injury of the cortical bone Two pairs of holes, 7 5 cm apart, were made anteriorly in both ends of the tibia, and the Silastic tube was fed into its position in the marrow cavity through these holes (Figure 1). The medullary material was replaced and covered by the fragment of cortex The periosteal incision was sutured, and the tube ends were fixed with a silk ligature The skin was closed over the tube ends with a continuous polypropylene suture and the wound was sealed with Nobecutan® spray *

For the measurements of tissue gas tensions the rabbits were lightly anesthetized with intramuscularly injected fentanyl citrate** and fluanison*** as described by Silver (1969) The ends of the tonometer were exposed through a small incision, and oxygen and carbon dioxide tensions in the healing bone were determined by the method of Kivisaari & Niinikoski (1973)

For continuous monitoring of tissue gases the gas permeable Silastic tube was repeatedly filled with hypoxic saline solution ($PO_2$ between 3 and 8 mmHg) for two minutes During this period $PO_2$ and $PCO_2$ equilibrations of 95 and 85 per cent were achieved between saline and the tissue in contact with the tube After the equilibration period the fluid was sampled into an Astrup type glass capillary tube

* Bofors, Nobel-Pharma, Sweden
** Fentanyl®, Orion, Helsinki, Finland
*** Sedalande®, Orion, Helsinki, Finland

by filling the tonometer with another dose of hypoxic saline from 1 ml syringe. The capillary was mounted into a micro sample injector*, and the sample was emptied into a thermostated cuvette containing either an $O_2$ or $CO_2$ electrode. The electrodes were connected with a gas monitor PHM 71.*

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Occlusion of the circulation to the leg by means of a tourniquet

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* Radiometer, Copenhagen, Denmark

** Diamox, Lederle, U.S.A.

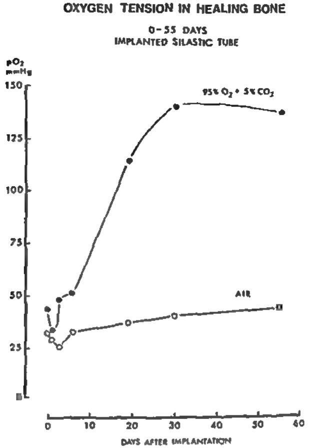



*Figure 2 Oxygen tensions in healing rabbit tibias Maximum tissue oxygen tensions during 1 h exposure to 95 per cent $O_2$ and 5 per cent $CO_2$ are also shown The figures represent single determinations*

decreased the bone $PO_2$ from baseline values to a minimum of 2–5 mmHg within a few minutes (Figure 4) At the same time the bone $PCO_2$ was elevated to values well above 100 mmHg After the release of circulation the gas tensions returned to normal levels in ten minutes

A low dose of acetazolamide (5–35 mg/kg) had no influence on the bone $PCO_2$, whereas a dose of 100 mg/kg given to three rabbits increased the mean $PCO_2$ of the healing bone from 68 to 101 mmHg within three hours on day 19

During air breathing the arterial blood $PO_2$ varied from 80 to 95 mmHg and the arterial blood $PCO_2$ was between 40 and 50 mmHg While the rabbit was breathing 95 per cent $O_2$ and 5 per cent $CO_2$ the $PaO_2$ was between 400 and 500 mmHg, and the $PaCO_2$ was approximately 70 mmHg Three hours after administration of acetazolamide there

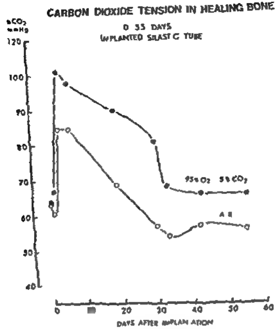



*Figure 3 Carbon dioxide tensions in healing rabbit tibias Maximum tissue carbon dioxide tensions during 1 h exposure to 95 per cent $O_2$ and 5 per cent $CO_2$ are also shown*

was a slight metabolic acidosis but the $PaCO_2$ remained essentially unchanged

On histologic examination, the Silastic tube was surrounded with a trabeculated structure of rapidly calcifying bone by the 19th day (Figure 5 a) On the 30th day, the trabeculation had greatly diminished By the 55th day further remodeling had taken place (Figure 5 b) The tonometer itself produced very little tissue reaction No dead space was noted around the tube and no tonometer became infected

## DISCUSSION

The significance of adequate oxygen supply in healing bone has been demonstrated both experimentally (Coulson et al 1966, Makley et al 1967, Prasad & Reynolds 1968, Wray & Rogers 1968), and with clinical proof (Slack et al 1965) Repair of fractures responds to changes in arterial oxygen tensions, and the main targets of oxygen in healing bone appear to be the synthesis of collagen and mineralization (Basset

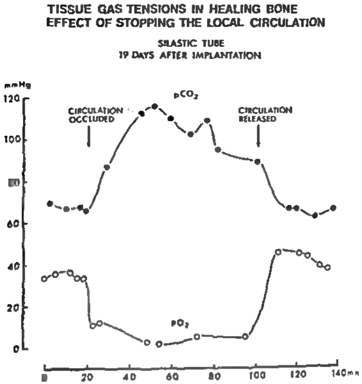
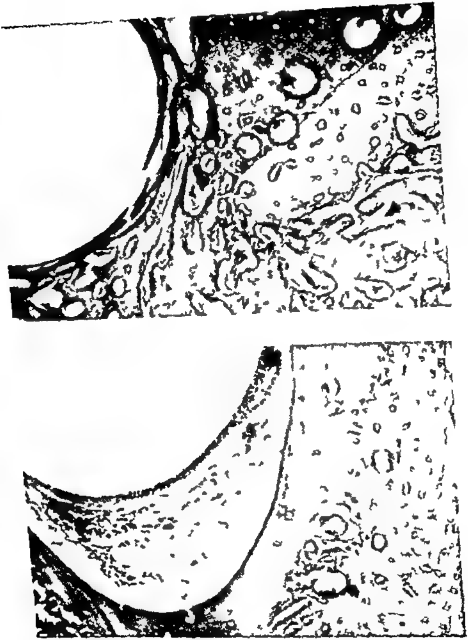



*Figure 4 Effect of occlusion of local circulation on tissue gas tensions in the healing rabbit tibia The measurement was performed 19 days after implantation of the Silastic tube*

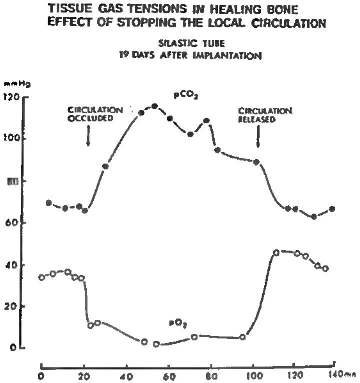
& Herrmann 1961, Yablon & Cruess 1968, Niinikoski et al 1970, Penttinen 1972)

The supply of oxygen to the repair area is diffusion-limited Measurements with ultramicro oxygen electrodes have shown that oxygen tension gradients are steep between the capillary and the healing tissue a few microns away (Silver 1969, Niinikoski et al 1972) A substantial portion of any injured tissue exists in conditions of low oxygen tension which may be far from optimal

In a study with semimicro needle electrodes Brighton & Krebs (1972) measured oxygen tensions below 10 mmHg in fracture hematoma whereas newly-formed cartilage and fiber bone showed oxygen tensions between 20 and 40 mmHg To the best of our knowledge, no study has been reported of the measurement of tissue carbon dioxide tension in healing bone According to Cuervo et al (1971), the $PCO_2$ in the extra-cellular fluid at calcifying sites of cartilage in rats varies between 38 and 43 mmHg Laurnen & Kelly (1969) observed no changes in the arterial-venous differences in oxygen content, $PO_2$, $PCO_2$ or pH



F g[illegible] a Phot m[illegible]og aph of the Silast c tube surrounded by t abeculated bone 19 days of[illegible] implantat on Hematoxyl n and eosin sta n (b) Silast c tube [illegible] the ma ro[illegible] av ty of the heal ng rabb t t b a 5[illegible] da s after mplantat on The inner [illegible] tex looks [illegible]rtually normal

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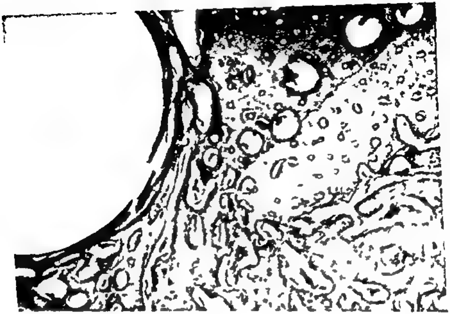

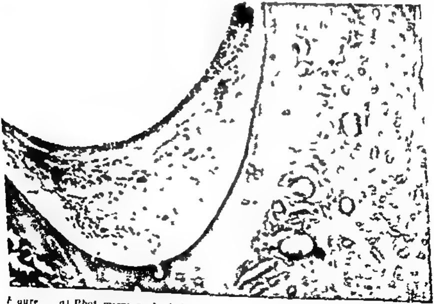

*Figure (a) Photomicrograph of the Silastic tube surrounded by trabeculated bone 13 days after implantation. Hematoxylin and eosin stain. (b) Silastic tube in the marrow cavity of the healing rabbit rib at 55 days after implantation. The inner cortex looks virtually normal.*

when blood from a fractured canine tibia was compared with that from the control side $O_2$ consumption and $CO_2$ *production, however, must* have increased since blood flow was invariably elevated at the fracture site Dulce et al (1960) suggested the presence of a functional carbonic anhydrase system in bone which could aid in the mineralization and demineralization of bone by controlling the local hydrogen ion secretion and pH

The present results are comparable to those of an earlier study in which tissue oxygen tensions in healing rabbit tibias were measured by continuous perfusion of the implanted Silastic tube (Niinikoski & Hunt 1972) The normal sequences of change in $PO_2$ (Figure 2) are identical and the responses to systemic hyperoxia are generally similar to the findings of the earlier method The advantages of the capillary sampling technique over continuous perfusion of the tonometer have been discussed elsewhere (Kivisaari & Niinikoski 1973)

The foreign body reaction that normally occurs around the Silastic tube consists normally of only two to four cell layers Blood vessels frequently lie within a distance of 40–50 $\mu$ from the tube The Silastic tubing perfused or filled with hypoxic saline solution measures and extracts oxygen from a distance of at least 1 0 mm (Kivisaari & Niinikoski 1973) Therefore, oxygen extracted into the sample probably derives not only from the marrow cavity but also from the inner cortex

The bone-healing model used in this study differs markedly from a normal fracture of the tibial shaft In the present model a small external callus is formed along the whole length of the tibia but the main process occurs in the marrow cavity Here the trauma site is filled with fibrous tissue which quickly calcifies (Figure 5 a) Possibly because of a good blood supply, cartilage formation does not occur, and fibrous or spongy bone is formed directly Remodeling is evident by the 30th day, and by the 55th day the bone looks almost normal (Figure 5 b)

During the first three days after implantation the bone $PO_2$ was rather low and its response to systemic hyperoxia was small (Figure 2) This was probably partly due to a transient reduction of local blood flow in the marrow cavity caused by clotting after the fresh trauma Between the third and 30th days the baseline $PO_2$ and the response to systemic hyperoxia increased gradually, probably due to the developing vascularity and the decreasing oxygen consumption in the repair tissue During the remodeling phase the bone oxygen tensions remained virtually unchanged

The high tissue carbon dioxide tensions between days 3 and 6 were probably due to accumulation of carbon dioxide because of impaired circulation and/or to increased production of carbon dioxide by the rapidly regenerating tissue (Figure 3) When the healing progressed the bone $PCO_2$ gradually decreased Between days 30 and 55 the bone $PCO_2$ was about 55 mmHg The increase of the bone $PCO_2$ during breathing of 95 per cent $O_2$ and 5 per cent $CO_2$ was proportional to the concomitant respiratory acidosis from the third day onwards

When the circulation in a limb was interrupted by a tourniquet, the bone $PO_2$ fell abruptly so that most of the decrease occurred within two minutes (Figure 4) After the occlusion of circulation the bone $PCO_2$ gained its maximum within the first 30 minutes and then declined slightly These results suggest marked oxygen consumption in the healing bone tissue When all available oxygen has been consumed no more carbon dioxide is accumulated After the tourniquet was removed the bone $PO_2$ increased momentarily above the normal level probably due to reactive hyperemia or transient decline in oxygen consumption

The local carbon dioxide tension may play a physiological role in the process of calcification Bone mineralization appears to occur in conditions of rather high tissue $PCO_2$ (cf Figure 3) High concentrations of carbonic anhydrase have been detected at calcifying sites of cartilage (Cuervo et al 1971) On the other hand, Minkin & Jennings (1972) showed that inhibitors of carbonic anhydrase inhibited parathyroid hormone induced resorption of bone in organ culture and suggested the presence of a functional carbonic anhydrase system in bone linked to the mechanism of bone resorption

In the present study intravenous administration of carbonic anhydrase inhibitor caused a marked rise in bone $PCO_2$ at the phase of rapid regeneration and calcification Simultaneously, the arterial blood $PCO_2$ remained unchanged suggesting that the rise in bone $PCO_2$ is due to a local effect of the carbonic anhydrase inhibitor

## SUMMARY

Tissue gas tensions were measured in healing rabbit tibias by means of an implanted Silastic tonometer During the course of the healing, tissue oxygen tensions increased progressively and carbon dioxide tensions underwent a gradual decline In all phases of repair, bone tissue gases responded to systemic hyperoxia and hypercarbia Occlusion of local circulation resulted in tissue anoxia and accumulation

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*Key words* fracture healing, oxygen analysis; carbon dioxide analysis; carbonic anhydrase, ossification

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of carbon dioxide Acetazolamide, an inhibitor of carbonic anhydrase elevated the carbon dioxide tension in the bone but not in the blood which supports earlier data indicating the presence of a functional carbonic anhydrase system in actively metabolizing bone tissue

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Two cases are reported, a 34 year-old man and a 2½-year-old boy, showing widespread osteolytic destruction of the costae and cervical vertebra and the ilium respectively

Biopsy from the involved bones revealed an overgrowth of small thin walled blood vessels, later the bone in the boy was transformed into a capillary rich fibrous tissue Both cases were treated by irradiation New bone was formed in the lesions after this treatment

For an accurate diagnosis of the disease a combination of the clinical and the radiographical picture and a histological examination of biopsy material is essential

## SUBCHONDRAL PRESSURE MEASUREMENTS BEFORE AND AFTER TIBIAL OSTEOTOMY FOR OSTEOARTHRITIS OF THE KNEE

*Ian Goldie Hakon Wetterquist & Olle Renberg* (Dept of Orthopaedic Surgery II, Sahlgren Hospital) Gothenburg

In osteoarthritis of the knee there is an interference with hemodynamic events Increased intramedullary pressures can be registered, which may cause pain Osteotomy decreases both pressure and pain

Pressure measurements have been made in 6 normal knees and 16 knees with osteoarthritis The latter measurements were taken before operation and 3 and 6 months after The pressure measurements were made by inserting a Gidlund needle into the intermedullary space 2 cm below the tibial plateau The pressure was recorded by capacitance transducers on a four channel recorder (Mingograph)

*Normal Knees* A wide distribution of values was recorded as previously reported by Arnoldi Range of distribution 10–25 mmHg

*Osteoarthritic knees* (n = 16)

*Before osteotomy* Range of distribution 20–70 mmHg

*Three months after operation* 20–40 mmHg

*Six months after operation* 20–50 mmHg

## RECONSTRUCTION OF THE KNEE JOINT WITH THE FREEMAN SWANSON PROSTHESIS

*Peter Herberts & Gunnar Andersson* (Dept of Orthopaedic Surgery II, Sahlgren Hospital) Gothenburg

Preliminary results were presented of 20 knee arthroplasties using the Freeman Swanson knee prosthesis Nineteen patients had severe rheumatoid arthritis, one patient had an advanced osteoarthrosis All patients were studied preoperatively and postoperatively at fixed time intervals in relation to the operation The operation was offered to those who were chair bound and to those patients who would accept an arthrodesis The follow up period varied from 6 to 24 months Pain, walking ability range of movement, flexion deformity and valgus or varus deformity combined with instability were evaluated In an attempt to make a total assessment of the procedure 75 per cent were graded as good (pain free, walking outdoors, range of movement from −5 to 90°, stable and varus or valgus deformity less than 10°) Twenty per cent were improved and graded as acceptable and only 5 per cent were deteriorated and graded as poor

Acta orthop scand 46, 280–283, 1975

# PROCEEDINGS OF THE SWEDISH ORTHOPAEDIC SOCIETY

## FALUN, SWEDEN, MAY 1974

### CIRCULATORY AND RESPIRATORY CHANGES DURING INTERMEDULLARY PROSTHETIC SURGERY

*Jan Modig, Christer Busch & Sven Olerud* (Dept of Orthopaedic Surgery, Academic Hospital) Uppsala

Patients submitted to total hip replacement surgery by the Charnley technique were studied Operations were performed under epidural analgesia In addition, an experimental study was carried out in which intravenous injections of acrylic monomers were administered to dogs during both controlled ventilation and spontaneous breathing Our studies indicate that circulatory and pulmonary dysfunction associated with certain steps in the total hip replacement procedure are mainly due to platelet and fibrin deposition in the lungs, i e intravascular coagulation, induced by the efflux of tissue thromboplastic products The appearance of bone marrow fat *per se* in the pulmonary circulation is of minor importance, and the release into the lungs of acrylic monomers is probably of no importance

### LATE RESULTS OF PERTHES' DISEASE IN TREATED AND UNTREATED CASES

*R Kalen* (Dept of Orthopaedic Surgery, Danderyds Hospital) Stockholm

A follow-up study of 60 cases of Perthes' disease recorded at the Norrbacka Institute from 1927 to 1938 was carried out The average follow-up period was 41 years Thirty-two patients had not been given any treatment, the remaining 28 had been treated mainly by immobilization in abduction or by traction and the use of crutches The two groups were investigated from the anamnestic, clinical and roentgenological point of view A difference between the two groups was noted, with the treated group having a slight advantage On the whole the patients were well off Two were on invalid pension because of the hip During the last three years only one had been out of work for a period The poor results were strictly related to a late onset

### DISAPPEARING BONE

*J Möller Nielsen* (Dept of Orthopaedic Surgery II, Sahlgren Hospital) Gothenburg
*I -G Kindblom* (Dept of Pathology II, Sahlgren Hospital) Gothenburg

The rare "disappearing bone" disease is characterized by spontaneous massive osteolysis and angiomatosis of one or several bones

Two cases are reported a 34 year old man and a 2½ year old boy, showing widespread osteolytic destruction of the costae and cervical vertebra and the ilium respectively

Biopsy from the involved bones revealed an overgrowth of small thin walled blood vessels later the bone in the boy was transformed into a capillary rich fibrous tissue Both cases were treated by irradiation New bone was formed in the lesions after this treatment

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## ARTHROPLASTY OF THE KNEE WITH CONDYLAR ENDOPROSTHESIS (MODIFIED GUNSTON)

*I Hult* (South Hospital) Stockholm

*Total material* 51 knees in 45 patients (both knees in 6 patients)

I *21 knees operated on and given a slightly modified Gunston prosthesis* (very close to the original)

a) 18 knees with severe rheumatic arthritis, all operated both medially and laterally

b) 3 knees with severe medial gonarthrosis with operation only in the medial condyles

Follow up 1–2 years

| | | |
|---|---|---|
| *Results* | Good or excellent | 14 |
| | Fair | 4 |
| | Poor | 4 |
| *Reop* | 2 arthrodeses (infection) | |
| | 2 osteotomies | |
| | 1 loosened tibial prosthesis | |
| | 1 subluxation | |
| | 1 exploration | |

II *30 knees operated on and given a more modified Gunston prosthesis*

Follow up 18 knees ½–1 year

12 knees less than ½ year (not estimated)

18 knees a) 8 severe rheumatoid arthritis (7 operated both medially and laterally and 1 only medially)

b) 10 gonarthrosis (9 medially and 1 laterally)

| | | |
|---|---|---|
| Results | Good or excellent | 16 |
| | Fair | 2 |
| | Poor | 0 |
| Reop | 0 | |

*Conclusions* The preliminary results of knee arthroplasty with a condylar prosthesis in rheumatoid arthritis and gonarthrosis are very promising and of the same order as TRA on hips with the Charnley prosthesis Our modification of the Gunston prosthesis makes the operation technically easier and the results safer

## OSTEOSYNTHESIS ACCORDING TO ENDER IN TROCHANTERIC FEMUR FRACTURES

*N Islander* (Central Hospital) Falun

Since Jan 1972 the Orthopaedic Department at Falun Hospital has adopted Ender's method for fixation of pertrochanteric femur fractures A study of 134 operated cases is discussed The merits of this method were seen as a short operating time little operative blood loss and early mobilization of the patients

The study concentrated on the complications 9 7 per cent died during the first 4 weeks 1 5 per cent sustained wound infection 13 4 per cent had distal nail gliding with disability 1 5 per cent had a relatively high rate of operative bleeding

Regarding distal nail gliding accompanied by disability eight cases had to be

reoperated before complete fracture healing (6 per cent) Ten cases had the nails extracted after fracture healing

## ENDER PINNING OF INTERTROCHANTERIC FRACTURES

*O Stenseth & L Soderberg* (Central Hospital) Östersund

Sixty intertrochanteric fractures have been treated by this method since September 1972 For the latter part of the period this method has been applied to all intertrochanteric fractures in our clinic

The results are classified as follows

| | |
|---|---|
| Good | 41 |
| Fair | 11 |
| Poor | 7 |

In spite of these not obviously brilliant results (this being partly ascribable to lack of experience) we consider the method recommendable as a routine method. Its advantages are

Simplicity
Swiftness
Minimal blood loss
Early ambulation

Acta orthop scand 46, 284, 1975

# FOLLOW-UP NOTES

The purpose of this letter is to point out an exception to one of our conclusions in the paper entitled "Analysis of Mechanical Symmetry in Rabbit Long Bones". We concluded in this paper that our observations on the mechanical properties of these bones were not incompatible with the assumption of mechanical symmetry allowing for basic biological variations However, one of the parameters observed in our data did show variation which would be unlikely to occur purely by chance Our recording of the angular deformation of the rabbit humeri on page 333, Table 2, shows a mean difference of 3 4 between the averages of the right humeri of these animals and the left humeri This variation is statistically significant at the 001 level

We do not have a good explanation for this one parameter being at variance with the distinct basic pattern of mechanical symmetry observed in seven other parameters

Ref Acta orthop scand 45, 321, 1974

Sincerely,
August A White III, M D
December 1974

Acta orthop. scand. 46, 283, 1975

# ORTHOPAEDIC REVIEWS 1975

Publishing reports on new observations within orthopaedic research and practice is claiming the full capacity of the regular Acta issues.

This special issue is a result of a joint effort of the boards of SICOT and of Acta Orthopaedica Scandinavica.

It is with pleasure that we take this opportunity to publish the SICOT reviews.

The authors are prominent colleagues who possess outstanding command of their subjects, and the articles offer excellent information on some most important areas which have been the focus of research and development in recent years. The editor wishes to thank the contributors for their cooperation.

The editor has found it justified to leave the reviewers more freedom than is applied to our regular issues. It may be known that the traditional volume of SICOT proceedings has been dispensed with.

An international editorial committee will in future provide the membership with current scientific and administrative information.

Acta is also accepting the new times. From January 1976 Acta will appear in a new format with double column pages and a new editorial structure.

KNUD JANSEN,
Editor

Acta orthop scand 46 286–314 1975

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# CALCIUM METABOLISM

Hector F DeLuca

Calcium is one of the most abundant metal ions found in all living organisms In the higher animal species its abundance can, for the most part, be attributed to its central role as a component of the structural elements or skeleton Ninety-nine per cent of all the calcium in man is deposited in the skeleton as hydroxyapatite However, the multiple non-structural functions of this divalent cation and its essentiality in some cases dictates that it must be very closely regulated For example, calcium ions are essential for nerve conduction, for muscle contraction and relaxation, for the structural integrity of cell membranes and for the adhesion of one cell to another It has other general functions, such as participating in the blood clotting mechanism and in certain enzymatic reactions It is, therefore, reasonable that its concentration in the extracellular fluid and intracellular fluid must be closely regulated and that a sufficient and continuing external source of calcium must be assured In terrestrial animals the infrequent intake of calcium has necessitated that the skeleton make available its calcium for the maintenance of extracellular fluid concentrations and that an efficient and regulated system of absorption be developed

Although much had been known about calcium metabolism in higher animals, within the past decade a new wealth of information has become available in this area, primarily because of the discovery of calcitonin, a hormone believed to be involved in calcium regulation, and the discovery that vitamin D is converted to at least one hormone which functions basically in control of calcium metabolism It will be the purpose of this review to bring into focus these new developments by

Some of the original research reported in this paper was supported by a contract from the U S Atomic Energy Commission No AT(11-1)-1668 and the Steenbock Fund of the University of Wisconsin Madison

presenting what is known concerning the mechanisms involved in calcium utilization and regulation

### *Intestinal calcium absorption*

Of basic importance to calcium physiology is the utilization of this important environmental element Terrestrial animals which are infrequently exposed to calcium have developed efficient mechanisms for its absorption from the intestinal tract and efficient conservation mechanisms in the kidney It is now known that calcium is absorbed throughout the small intestine and there has been some discussion as to which segment of the intestine accounts for the major portion of calcium utilized It seems clear that the upper duodenum has the most efficient mechanism for calcium transport, but that the bulk of calcium is absorbed in the remainder of the small intestine, simply because of the length of time during which calcium is exposed to that portion of the intestine (Harrison & Harrison 1960, Schachter & Rosen 1959, Lengman 1963)

### *The role of vitamin D*

The most important factor in determining the rate of calcium absorption in all segments of the intestine is vitamin D Very recently, Harrison & Harrison have clearly shown that vitamin D stimulates intestinal calcium absorption in all segments of the small intestine and in the colon as well (Harrison & Harrison 1969) Although it had been believed for many years that vitamin D must function directly in the small intestine without metabolic change (Schachter et al 1964, Kodicek 1960), recent evidence has clearly demonstrated that under physiologic circumstances it must be metabolically converted to an active form before it stimulates intestinal calcium absorption (DeLuca 1974) As shown in Figure 1, vitamin D, which can be derived either from the diet or from ultraviolet irradiation of skin, first progresses to the liver where it undergoes hydroxylation on carbon 25 to produce 25 hydroxyvitamin $D_3$ (25 OH $D_3$) This reaction occurs predominantly in the microsomal fraction of the endoplasmic reticulum [illegible] NADPH + [illegible] Since this r[illegible] cytochrome [illegible] [illegible]cation (Horsting & DeLuca 1969) This reaction is feed back regulated by the liver level of 25 OH-$D_3$ itself (Bhattacharyya & DeLuca 1973) Thus as the liver 25 OH $D_3$ is utilized,

Acta orthop scand 46 286–314 1975

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# CALCIUM METABOLISM

HECTOR F DELUCA

Calcium is one of the most abundant metal ions found in all living organisms In the higher animal species its abundance can, for the most part, be attributed to its central role as a component of the structural elements or skeleton Ninety-nine per cent of all the calcium in man is deposited in the skeleton as hydroxyapatite However, the multiple non-structural functions of this divalent cation and its essentiality in some cases dictates that it must be very closely regulated For example calcium ions are essential for nerve conduction, for muscle contraction and relaxation, for the structural integrity of cell membranes and for the adhesion of one cell to another It has other general functions, such as participating in the blood clotting mechanism and in certain enzymatic reactions It is, therefore, reasonable that its concentration in the extracellular fluid and intracellular fluid must be closely regulated and that a sufficient and continuing external source of calcium must be assured In terrestrial animals the infrequent intake of calcium has necessitated that the skeleton make available its calcium for the maintenance of extracellular fluid concentrations and that an efficient and regulated system of absorption be developed

Although much had been known about calcium metabolism in higher animals, within the past decade a new wealth of information has become available in this area, primarily because of the discovery of calcitonin, a hormone believed to be involved in calcium regulation and the discovery that vitamin D is converted to at least one hormone which functions basically in control of calcium metabolism It will be the purpose of this review to bring into focus these new developments by

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Some of the original research reported in this paper was supported by a contract from the U S Atomic Energy Commission No AT(11–1) 1668 and the Steenbock Fund of the University of Wisconsin Madison

ported in this manner (Bikkers & DeLuca 1967, Edelstein et al 1973, Belsey et al 1974) The 25 OH $D_3$ represents the most abundant metabolite of vitamin D found in the blood and may be considered the circulating form of vitamin D (Ponchon & DeLuca 1969) So far no direct function has been demonstrated for this metabolite and instead it progresses to the kidney where it undergoes hydroxylation on carbon 1 to form 1,25-dihydroxyvitamin $D_3$( 1,25-$(OH)_2D_3$) (Holick et al 1971, Fraser & Kodicek 1970) This hydroxylation occurs in the mitochondria of renal cells and requires molecular oxygen and internally generated NADPH (Gray et al 1972, Ghazarian & DeLuca 1974) Very recently, clear evidence has been obtained that this reaction involves a specific cytochrome P-450 (Ghazarian et al 1974) This hydroxylation reaction is strongly feed back regulated, as will be described below

The 1,25-$(OH)_2D_3$ has now been shown to be at least one of the metabolically active forms of vitamin D in the intestine (Boyle et al 1972 a Wong et al 1972) The kidney is the sole site of production of this important metabolite, and hence renal tissue is essential for vitamin D to exert its characteristic effects on the intestine, bone and elsewhere Recent work with radioactive 1,25 $(OH)_2D_3$ has provided evidence that this compound is probably not further metabolized before it functions in the small intestine and in bone (Frolik & DeLuca 1971, 1972) Because its production is regulated in a negative manner by serum calcium concentration working through the parathyroid gland, one must consider 1,25 $(OH)_2D_3$ a hormone derived from vitamin D whose primary function is in the utilization or mobilization of calcium from intestine and bone (Boyle et al 1972 b Garabedian et al 1972)

*Receptor hypothesis of 1,25 $(OH)_2D_3$ function in intestine*

The 1,25-$(OH)_2D_3$ progresses to the intestine, where presumably it enters the columnar epithelial cells of the villi and appears in the nuclear "fraction" (*Figure 2*) (Haussler et al 1968, Chen et al 1970) So far no clear evidence has been provided which would prove conclusively that all of the 1,25-$(OH)_2D_3$ of the nuclear fraction is located in the nucleus itself Autoradiography has not been performed to demonstrate this and by subcellular fractionation techniques, only crude nuclei have been prepared This fraction contains not only nuclei, but also brush border membranes, other cell fragments, plasma membrane and debris Attempts to obtain highly purified intestinal nuclei

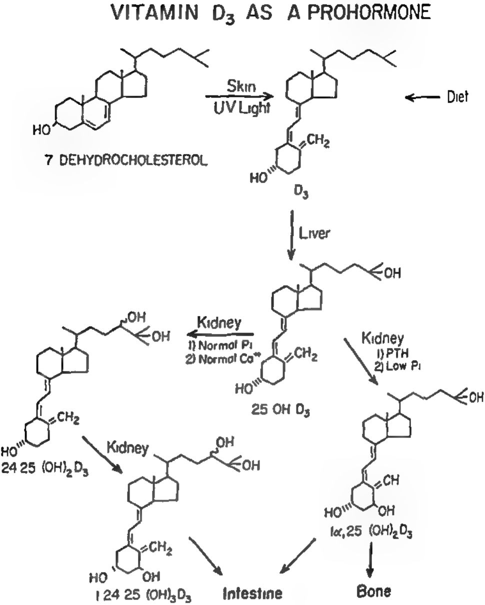


*Figure 1 Diagrammatic representation of the biogenesis and metabolism of vitamin $D_3$*

its disappearance causes a release of the 25-hydroxylase to produce additional amounts of this important metabolite The regulation is such that the circulating level of 25-OH-$D_3$ in the blood is of the order of 25–40 ng/ml This level can be raised by the administration of large amounts of vitamin D to levels of as high as 1200 ng/ml (Haddad & Stamp 1974)

The 25-OH-$D_3$ is bound to an $\alpha^2$-globulin of the plasma and is trans-

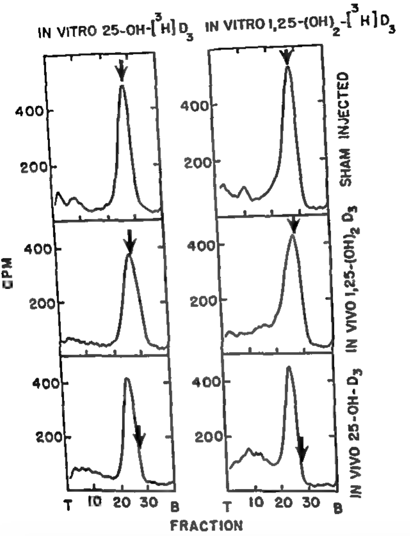


*Figure 3* Intestinal mucosa cytosol binding of either $^3$H-1,25-(OH)$_2$D$_3$ or $^3$H-25-OH-D$_3$. Vitamin D-deficient rats were bilaterally nephrectomized to prevent conversion of $^3$H-25-OH-D$_3$ to $^3$H-1,25-(OH)$_2$D$_3$. They were then injected with 0.05 ml ethanol, 0.05 ml ethanol containing 650 pmole 1,25-(OH)$_2$D$_3$ or the ethanol containing 650 pmole 25-OH-D$_3$. One hour later the intestinal cytosol was prepared and incubated with either 3 pmole $^3$H-25-OH-D$_3$ or 3 pmole $^3$H-1,25-(OH)$_2$D$_3$. Samples were then analyzed on a linear 10–30 per cent density gradient centrifugation system. The arrows indicate the position of sedimentation of $^3$H-1,25-(OH)$_2$D$_3$ and $^3$H-25-OH-D$_3$ binding protein (Knutson et al 1975). Note that predosing with 25-OH-D$_3$ but not with 1,25-(OH)$_2$D$_3$ prevents binding in vitro to the 6S protein labeled with the arrow.

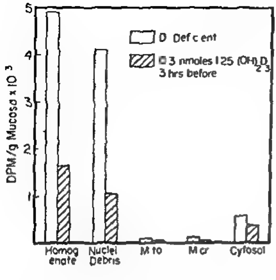


*Figure 2 Subcellular location of $^3H$-1 25-$(OH)_2D_3$ in intestinal mucosa Vitamin D deficient rats were divided into two groups One group received 0 3 nmoles 1,25-$(OH)_2D_3$ intravenously in 0 02 ml ethanol 3 hours before receiving 0 3 nmoles $^3H$ 1 25-$(OH)_2D_3$ (▨) while the other group received the 0 02 ml of ethanol 3 hours before receiving the $^3H$-1,25-$(OH)_2D_3$ (□) The rats were killed 3 hours after receiving the $^3H$-1,25-$(OH)_2D_3$ and the cell fractions prepared (Chen & DeLuca 1973, reproduced with the kind permission of the publisher)*

have been frustrated by technical difficulties So far pure nuclei in yields of only 20 per cent can be obtained from intestinal mucosa and thus it is not possible to fully examine the question of whether the 1,25-$(OH)_2D_3$ which appears in the nuclear fraction is in fact associated with the nuclei In any case, somewhere in the neighborhood of 80 per cent of administered 1,25-$(OH)_2D_3$ appears in the nuclear fraction There have been attempts, primarily by Haussler and coworkers, to demonstrate that 1,25 $(OH)_2D_3$ acts in a fashion similar to that described for other steroid hormones, namely that it becomes associated with a 3 5 S cytoplasmic receptor which becomes converted to a larger receptor in becoming bound to chromatin of the nucleus (Brumbaugh & Haussler 1974 a, b) Although this concept is appealing inasmuch as it would be consistent with existing dogma on the function of steroid hormones, proof that this mechanism actually occurs is far from complete In rat intestine the only protein which has been shown to bind 1,25 $(OH)_2D_3$ is a 6S component (Knutson et al 1975 Haddad & Birge 1971) This component prefers binding 25-OH $D_3$ to 1,25-$(OH)_2D_3$ Recent work has demonstrated that the 6S protein does not bind 1,25-$(OH)_2D_3$ *in vivo* and hence cannot represent a receptor for 1,25-$(OH)_2D_3$ in the initiation of intestinal calcium transport (Knutson et al 1975) The administration of saturating amounts of 1,25 $(OH)_2D_3$ *in vivo* will not prevent the binding of radioactive 25 OH-$D_3$ to the 6S component of cytoplasm incubated *in vitro* On the other hand, administration of saturating amounts of 25-OH-$D_3$ will prevent the *in vitro* binding of radioactive 1,25-$(OH)_2D_3$ to the 6S component (Figure 3) Since 1,25 $(OH)_2D_3$ and not 25 OH-$D_3$ is the

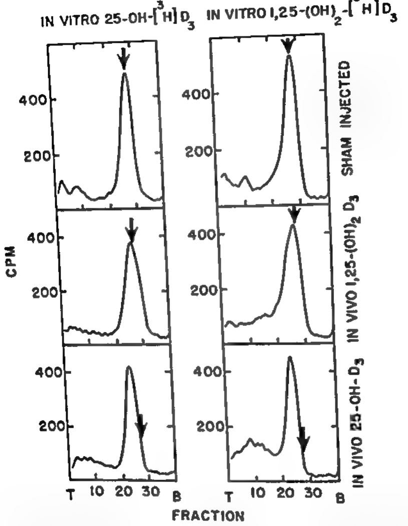


*Figure 3* Intestinal mucosa cytosol binding of either $^3$H-1,25-$(OH)_2D_3$ or $^3$H 25-OH-$D_3$. Vitamin D-deficient rats were bilaterally nephrectomized to prevent conversion of $^3$H-25-OH-$D_3$ to $^3$H-1,25-$(OH)_2D_3$. They were then injected with 0.05 ml ethanol, 0.05 ml ethanol containing 650 pmole 1,25-$(OH)_2D_3$ or the ethanol containing 650 pmole 25-OH-$D_3$. One hour later the intestinal cytosol was prepared and incubated with either 3 pmole $^3$H 25-OH-$D_3$ or 3 pmole $^3$H-1,25-$(OH)_2D_3$. Samples were then analyzed on a linear 10-30 per cent density gradient centrifugation system. The arrows indicate the position of sedimentation of $^3$H-1,25-$(OH)_2D_3$ and $^3$H 25-OH-$D_3$ binding protein (Knutzon et al 1975). Note that predosing with 25-OH-$D_3$ but not with 1,25-$(OH)_2D_3$ prevents binding in vitro to the 6S protein labeled with the arrow.

active form in stimulating intestinal calcium transport, it is evident that this cytosolic component cannot be functioning as a receptor in this system. Since the 3.5S component reported in chick intestinal cytosol (Brumbagh & Haussler 1974 a) has not been found in rat intestinal mucosa, it is not yet possible to accept the idea that there exists a 3.5S component which serves as the receptor for 1,25-$(OH)_2D_3$, at least not in mammals. Intense work is continuing in this area and further information on this undoubtedly will be available in the not too distant future.

### *Possible role of 1,25-$(OH)_2D_3$ in transcriptional mechanism*

The mechanism whereby 1,25-$(OH)_2D_3$ stimulates intestinal calcium transport is not at all clear at the present time. Early work with actinomycin D demonstrated that its prior administration to rats or chicks prevents vitamin D from initiating intestinal calcium transport (Zull et al. 1965, Norman 1965). This led to the idea that vitamin D must carry out its function in the intestine by interacting with the nucleus to stimulate retrieval of genetic information and synthesis of the proteins which then participate in intestinal calcium transport. This concept has persisted for 1,25-$(OH)_2D_3$. However, the question of whether actinomycin D will block 1,25-$(OH)_2D_3$ induced intestinal calcium transport remains controversial. Both actinomycin D (Tanaka et al. 1972) and cycloheximide (Tanaka et al. 1972, Tsai et al. 1973) when administered to vitamin D-deficient rats will bring about a diminution of the 25-OH-$D_3$-1$\alpha$-hydroxylase of kidney tissue. Thus the administration of actinomycin D to animals prior to the administration of vitamin D could have blocked intestinal calcium transport by inhibiting renewal of the 1$\alpha$-hydroxylase enzyme. Since the 1$\alpha$-hydroxylase enzyme has a half-life of the order of 2–4 hours, this is not an unlikely possibility. When actinomycin D is given 2 hours prior to the administration of 1,25-$(OH)_2D_3$ to vitamin D-deficient rats, intestinal calcium transport is initiated virtually as well as in animals not given antibiotic (Tanaka et al. 1971) (Figure 4). To illustrate that the antibiotic was functional in these experiments, the action of 1,25-$(OH)_2D_3$ in mobilizing calcium from bone was completely blocked by that antibiotic in the same animals (Tanaka & DeLuca 1971). The question nevertheless remains as to whether actinomycin D does progress to the intestinal cells which are responsive to 1,25-$(OH)_2D_3$. Quite opposite results have been obtained in the chick in which actinomycin

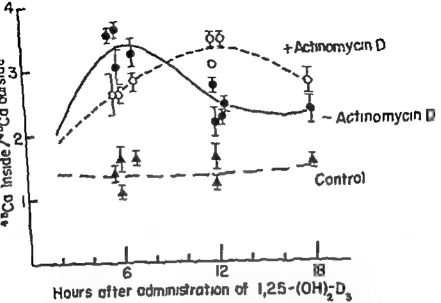


*Figure 4 Intestinal calcium transport response to 1,25-(OH)$_2$D$_3$ of vitamin D deficient rats given actinomycin D Vitamin D deficient rats were given 1 μg/g of actinomycin D 2 hours before they were given 650 pmole 1,25-(OH)$_2$D$_3$ while controls received either no 1,25-(OH)$_2$D$_3$ and actinomycin D or no actinomycin D Intestinal calcium transport was measured in vitro at various times after 1,25-(OH)$_2$D$_3$ dosing*

D was given every 2 hours prior to and during the administration of 1 25 (OH)$_2$D$_3$ (Tsai et al 1973) Although the intestinal calcium absorption response to 1,25 (OH)$_2$D$_3$ was blocked, such a protocol is extremely toxic especially to chickens The experience in our laboratory is that when actinomycin D is given at concentrations not toxic to chickens the 1 25-(OH)$_2$D$_3$ stimulated intestinal calcium transport is not blocked (Omdahl & DeLuca 1973 and unpublished results) No matter which experiment proves to be correct, interpretation of mechanisms in whole animals with the use of toxic antibiotics is risky at best Corradino has reported that the 1,25 (OH)$_2$D$_3$ stimulation of calcium binding protein in tissue culture is blocked by actinomycin D and α-amanitin (Corradino 1973) Likely induction is taking place in this system which uses embryonic intestine not yet developed but it is a great extrapolation that this reflects the situation in a vitamin D deficient chicken with a fully developed intestine It must therefore remain that the mechanism whereby intestinal calcium transport is

initiated by $1,25\text{-}(OH)_2D_3$ is not at all settled and although the most favorable concept of $1,25\text{-}(OH)_2D_3$ action is that involving retrieval of genetic information and protein synthesis, much work remains to be done before this can be established clearly.

*Transfer of calcium across the epithelial cell*

The mechanism of calcium transport across the cell is also not settled. There is no doubt that calcium is transported actively against an electrical and a concentration gradient. Although there is almost complete agreement that vitamin D increases the transfer of calcium across the brush border surface (Omdahl & DeLuca 1973), there is less agreement as to whether vitamin $D_3$ is involved in the serosal transfer of calcium (Schachter et al. 1966, Martin & DeLuca 1969 a). How vitamin D brings about the transfer of calcium across the brush border surface is also entirely speculative. Wasserman and his colleagues have demonstrated that vitamin D and more recently $1,25\text{-}(OH)_2D_3$ brings about the appearance of a calcium binding protein in intestine (Wasserman & Taylor 1966, Wasserman 1970). This protein, which has a molecular weight in the neighborhood of 24,000 in chicks (Wasserman 1975 a) and in mammals in the neighborhood of 8–12 000 (Drescher & DeLuca 1971 a), binds aproximately 4 calcium ions per molecule of protein. Although there is evidence that this protein is formed in the goblet cells (Taylor & Wasserman 1970), there is some reason to question that information. In any case, its participation in calcium transport is supported by the idea that calcium absorption rate is in a very rough way correlated with the amount of calcium binding protein present (Ebel et al. 1969, Wasserman 1970). Additionally the fact that the protein binds calcium and appears only after vitamin D also gives support to the idea of its participation in calcium transport. However, no experiment has satisfactorily demonstrated its clear involvement in the transfer process. Furthermore, there is no quantitative relationship between the amount of this protein and the calcium transport rate (Harmeyer & DeLuca 1969, Wasserman 1975 a). A most striking discrepancy is the time course of calcium binding protein levels in the intestine of chick after $1,25\text{-}(OH)_2D_3$ administration. Twenty four hours after $1,25\text{-}(OH)_2D_3$, intestinal calcium absorption has diminished to rachitic levels while the calcium binding protein level remains high (Wasserman 1957 a, Norman 1974), suggesting some other controlling factor or that the calcium binding protein is a con-

sequence of, rather than a participant in, calcium absorption Another system which could account for the vitamin D induced transfer of calcium across the brush border surface is the activation of a calcium dependent adenosine triphosphatase (Martin et al 1969, Melancon & DeLuca 1970) Although this enzyme has been suggested to be identical with the alkaline phosphatase of the brush border, its appearance and that of alkaline phosphatase does not correlate well with the initiation of intestinal calcium transport Whether it is involved then in calcium transfer therefore remains controversial

There has been much work regarding the biogenesis of chick calcium binding protein and the possible role of 1,25-$(OH)_2D_3$ in initiating this synthesis Although many attempts have been made to demonstrate the incorporation of radioactive amino acids in the calcium binding protein following stimulation by some form of vitamin D, the results have been disappointing (Drescher & DeLuca 1971 b Bruns & Avioli 1975) Some work by MacGregor et al (1970) has shown a stimulation of radio active amino acid incorporation into the calcium binding protein by vitamin D although it was necessary to manipulate the deficient chickens in such a way as to make interpretation of the experiment unclear More recently Emtage et al (1973) and Lawson & Emtage (1974) have studied the synthesis of calcium binding protein by polysomes isolated from the intestines of chicks given vitamin D as compared to rachitic chickens They found that the polysomes from the vitamin D treated chickens synthesize calcium binding protein *in vitro*, whereas those from the deficient chicks do not Calcium binding protein was detected by immunological methods and hence there seems little doubt that they are in fact measuring synthesis of the calcium binding protein or a related protein Since chicks given vitamin D must synthesize the calcium binding protein backbone it is not surprising to find that polysomes from vitamin D treated chicks synthesize calcium binding protein The key question must, therefore, remain what is the sequence of events leading to the appearance of the calcium binding protein and what is its relationship to calcium transport?

The role of mitochondria in the transfer of calcium has also received a good deal of attention There is no doubt that at calcium concentrations about $10^{-7}$ M mitochondria will actively take up calcium (DeLuca & Engstrom 1961 Vasington & Murphy 1962, Rossi & Lehninger 1964) This is believed to play an important role in calcification and may well be an important mechanism to prevent intracellular damage by high calcium concentrations It may also be a mechanism whereby calcium

can be transferred through the cell without damaging the enzymatic and metabolic machinery Whether mitochondria actually participates as a calcium shuttle remains unknown, although it represents an interesting idea (Omdahl & DeLuca 1973)

Sodium ions are required for intestinal calcium transport (Martin & DeLuca 1969 b, Harrison & Harrison 1963) In contrast to the role of sodium in glucose and amino acid transport, sodium is required for the serosal transfer of calcium Its participation is not defined, although a suggestion that it provides a concentration driven exchange mechanism for calcium at the basal-lateral membrane has been made (Omdahl & DeLuca 1973)

A new compound which has a marked effect on calcium absorption is found in extracts of a toxic plant *Solanum malacoxylon* (Wasserman 1975 b) This substance, which apparently has a molecular weight of over 2000, initiates calcium transport (Wasserman 1975 b, Uribe et al 1974) and stimulates the appearance of calcium binding protein (Wasserman 1975 b). This has led to the suggestion that it represents a plant source of 1,25-$(OH)_2D_3$ (Wasserman 1974) However, unlike 1,25-$(OH)_2D_3$, it does not mobilize calcium from bone (Uribe et al 1974), is aqueous soluble and is stable in oxygenated aqueous solutions, all of which make it unlikely that it is 1,25-$(OH)_2D_3$ Rather it may illustrate the lack of specificity of the intestinal calcium transport system

The mechanism of intestinal calcium transport then remains relatively undefined and must be regarded as unsettled Figure 5 demonstrates the variety of possible mechanisms involving the active form of vitamin D The 1,25-$(OH)_2D_3$ may or may not interact with a receptor in the cytosol and may or may not be transferred to the nucleus where it may initiate the transcription of specific genes coding for calcium transport proteins The messenger then can be read out by the polysomes yielding the proteins which participate in intestinal calcium absorption Alternatively, 1,25-$(OH)_2D_3$ may function at the polysome level to initiate translation of functional proteins and calcium transport or it may function directly at the brush border membrane It may also participate in the conversion of precursor protein to calcium transport proteins The true transport protein may or may not be the calcium binding protein In any case the brush border membrane is rendered permeable to calcium which upon entering the cell is sequestered perhaps by the mitochondria The mitochondria can shuttle calcium to the basal-lateral membrane, where a deficient level of

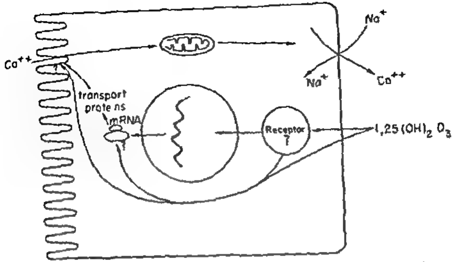


*Figure 5 Diagrammatic sketch of known and hypothesized events in the $1,25\text{-}(OH)_2D_3$ stimulation of intestinal calcium transport*

calcium brings about release of the intramitochondrial calcium Calcium is then expelled through the basal lateral membrane by a downhill sodium gradient which exchanges for the calcium Alternatively, studies with lanthanum suggest that calcium may not even enter the cell during transfer and may be transferred from the brush border directly to the basal lateral membrane (Wasserman 1975 a) It is obv ous that much remains to be learned concerning the mechanism of intestinal calcium transport and the role of vitamin D in initiating this process

### *Regulation of intestinal calcium absorption by dietary calcium and phosphorus*

A great deal of progress has been made in understanding the mechanism of regulation of intestinal calcium transport by dietary calcium and by the skeletal needs for calcium Early work by Rottensten (1938), by Fairbanks & Mitchell (1936) and the definitive work of Nicolaysen et al (1953) clearly demonstrated that animals or man placed on a low calcium diet have a markedly elevated rate of intestinal calcium absorption On the other hand animals or humans placed on a high calcium diet have markedly reduced rates of intestinal calcium absorption I urthermore, it can be shown that animals or man requiring

calcium for skeletal growth or calcification have markedly elevated intestinal calcium absorption. In fact, Nicolaysen and coworkers demonstrated that prisoners placed on a low calcium diet develop highly efficient intestinal calcium absorption which persisted even after they were placed on an adequate calcium intake. This high efficiency of absorption persisted until their bones, which had been demineralized by the low calcium diet, were completely recalcified. Nicolaysen reasoned that some endogenous factor or hormone must be secreted in response to the need for calcium and stimulates the intestine to absorb the cation. Nicolaysen found further that the appearance of the endogenous factor in the regulation of intestinal calcium absorption requires the presence of vitamin D. With the discovery that vitamin D must be metabolically converted to 25-OH-$D_3$ in the liver, followed by conversion to 1,25-$(OH)_2D_3$ in the kidney before it can function in the intestine, came the concept that dietary calcium and the need for calcium might well regulate the synthesis of the active form of vitamin D. The first clear evidence for this idea was provided by the work of Boyle et al. (1971) in which the effect of dietary calcium in rats both deficient and given vitamin D on the *in vivo* generation of 1,25-$(OH)_2D_3$ was studied. They demonstrated quite clearly that rats maintained on a low calcium diet synthesize large amounts of 1,25-$(OH)_2D_3$. As dietary calcium is increased, the synthesis of 1,25-$(OH)_2D_3$ is shut down. However, in the vitamin D-deficient animals, it is clear that the regulation of 1,25-$(OH)_2D_3$ synthesis from a single dose of $^3$H-25-OH-$D_3$ by dietary calcium does not take place. It was discovered at the same time that as the synthesis of 1,25-$(OH)_2D_3$ is shut down by dietary calcium, another metabolite, 24,25-dihydroxy-vitamin $D_3$ (24,25-$(OH)_2D_3$) (Holick et al. 1972 b), is synthesized. The exact role of the 24,25-$(OH)_2D_3$ in calcium metabolism, if any, has not yet been established.

Utilizing the chicken, additional work has shown that kidney mitochondria will synthesize 24,25-$(OH)_2D_3$ when they are isolated from chickens maintained on a diet high in calcium plus vitamin $D_3$, whereas they will synthesize 1,25-$(OH)_2D_3$ when they are maintained on a diet low in calcium supplemented with vitamin $D_3$ (Omdahl et al. 1972, Knutson & DeLuca 1974). Furthermore, Omdahl & DeLuca (1971, 1972) have demonstrated that strontium inhibits intestinal calcium absorption by blocking the synthesis of 1,25-$(OH)_2D_3$. These results led to the concept that 1,25-$(OH)_2D_3$ might in part represent Nicolaysen's endogenous factor and might well be the message that the intestine receives in response to a need for calcium. Proof that this is the case

has been obtained in animals maintained on either 25-OH-$D_3$ or 1,25-$(OH)_2D_3$ as their sole source of vitamin D (Omdahl & DeLuca 1973, Ribovich & DeLuca, unpublished results) Chicks given the 25 OH-$D_3$ show a markedly elevated intestinal calcium absorption rate when a diet low in calcium is fed and a diminished rate when high calcium or strontium diet is fed On the other hand, animals given 1,25 $(OH)_2D_3$ show a high rate of intestinal calcium absorption quite independent of dietary calcium and strontium (Omdahl & DeLuca 1973) Similar results have been obtained with the rat (Ribovich and DeLuca, unpublished results) (Table 1) Thus it seems that regulation of intestinal calcium transport by dietary calcium or the need for calcium is mediated by the regulation of 1,25-$(OH)_2D_3$ synthesis and that 1,25-$(OH)_2D_3$ itself may represent the endogenous factor Nicolaysen described (Boyle et al 1972 b)

*Table 1 Stimulation of intestinal calcium transport by low calcium and low phosphorus diets*

| | Transport ratio $^{45}Ca$ serosal medium/$^{45}Ca$ mucosal medium | |
|---|---|---|
| | Vitamin $D_3$ | 1,25-$(OH)_2D_3$ |
| High calcium normal phosphorus | 2 3 ± 0 3 | 3 7 ± 0 5 |
| Low calcium normal phosphorus | 3 4 ± 0 1 | 3 8 ± 0 3 |
| High calcium low phosphorus | 6 5 ± 0 5 | 6 7 ± 0.3 |

Rats were fed the various diets for 3 weeks At 2 weeks they received a daily oral dose of either vitamin $D_3$ (25 ng) or 1,25-$(OH)_2D_3$ (12 5 ng) in 0 1 ml propylene glycol for 1 week. They were killed 24 hours after the last dose and intestinal calcium transport determined (Martin & DeLuca 1969 a)

Another important factor in the regulation of intestinal calcium absorption is the dietary phosphorus level Carlsson (1953) initially demonstrated that rats on a low phosphorus diet have a markedly elevated intestinal calcium absorption rate This was further established by the work of Morrissey & Wasserman (1971) and was confirmed by the work of Tanaka et al (1973) Of great interest is that phosphate deprivation, even in the absence of parathyroid glands brings about a stimulation of 1,25-$(OH)_2D_3$ synthesis (Tanaka & DeLuca 1973) Furthermore it could be shown that the intes[illegible]

rats maintained on low phosphorus diets which develop high rates of intestinal calcium absorption also accumulate large amounts of 1,25-(OH)$_2$D$_3$ (Tanaka & DeLuca 1973) It seemed possible therefore that the regulation of intestinal calcium transport by phosphate deprivation might well be through the stimulation of 1,25-(OH)$_2$D$_3$ synthesis However, in experiments in which rats were given 1,25-(OH)$_2$D$_3$ from exogenous sources, it is evident that they still show an elevated intestinal calcium absorption when they are given phosphate deficient diets (see Table 1) Thus the stimulation of intestinal calcium absorption by phosphate deprivation is not solely due to the regulation of 1,25-(OH)$_2$D$_3$ synthesis, but some other unknown factor or metabolic event must be involved This has not as yet been determined

## *Regulation of intestinal absorption by parathyroid hormone, calcitonin and glucocorticoids*

The question of whether there are other hormones that might affect vitamin D metabolism can obviously be raised Work by Garabedian et al (1974) has shown that the 1,25-(OH)$_2$D$_3$ stimulated intestinal calcium transport does not require the presence of parathyroid hormone nor its activity enhanced by the presence of this peptide hormone Furthermore, work being carried out by others with radioactive parathyroid hormone has shown that the intestine is not a target of parathyroid hormone action and the parathyroid hormone is not bound to that tissue (Zull & Repke 1972, Neuman, unpublished results) It therefore seems clear that the parathyroid hormone does not play a role directly on intestinal calcium transport As will be shown in a later section, in response to the need for calcium, it is the parathyroid glands which sense the serum calcium concentration and secrete the parathyroid hormone Parathyroid hormone in some unknown way proceeds to the kidney, where it stimulates the synthesis of 1,25-(OH)$_2$D$_3$ It seems clear then that the reported effects of parathyroid hormone on intestinal calcium transport are mediated by its role in the stimulation of the synthesis of the active form of vitamin D for that process Therefore, chronic hypoparathyroidism is probably associated with reduced intestinal calcium absorption and an inappropriate response of the intestine to calcium deprivation (Avioli et al 1974)

It is not at all certain to what extent calcitonin plays a role in the regulation of intestinal calcium transport *In vitro* experiments using vascularly perfused intestine have shown that calcitonin does inhibit

intestinal calcium absorption (Olson et al 1972) Work in intact animals however has not been uniform in this regard and it is uncertain to what extent calcitonin inhibits intestinal calcium transport *in vivo* It seems likely that the major effect of calcitonin is on the bone rather than the gastrointestinal tract as far as calcium is concerned

Finally some mention should be made of the glucocorticoids and their effect on intestinal calcium absorption Harrison & Harrison (1960) demonstrated that cortisone could reduce intestinal calcium transport This was taken as a mechanism which might reflect the glucocorticoids ability to counteract vitamin D toxicity Although this is probably not the case the mechanism whereby the glucocorticoids can reduce intestinal calcium absorption is of some interest It has been postulated that the glucocorticoids might interfere with vitamin D metabolism thereby reducing the amount of 1 25 (OH) $D_3$ reaching the intestine (Avioli et al 1968) However Kimberg and associates have provided data which indicate that corticoids reduce intestinal calcium transport in animals given exogenous 1,25 $(OH)_2D_3$ (Kimberg et al 1971) Furthermore they failed to demonstrate any effect of the glucocorticoids on the metabolism of vitamin D to the 1 25-(OH) $D_3$ (Favus et al 1973a b) On the other hand very recent work from Rasmussen s laboratory has shown that the glucocorticoids might well induce the conversion of 1 25 (OH) $D_3$ in the intestine to a more polar but inactive metabolite (Carre et al 1974) It seems strange that this was not observed by Kimberg and associates but nevertheless might account for the glucocorticoid reduced intestinal calcium absorption Only further investigation will provide the answer to this important question

## MOBILIZATION OF CALCIUM FROM BONE

### *Role of parathyroid hormone*

Another important site is the mobilization of calcium from bone There is a massive amount of literature which clearly illustrates that the parathyroid hormone both *in vivo* and *in vitro* will mobilize calcium from bone The mechanism of this mobilization of calcium remains unknown in spite of a great deal of intensive investigation Although attempts have been made to demonstrate that the parathyroid hormone brings about these changes by stimulating RNA and protein synthesis these results are inconclusive (Park & Talmage 1968) In fact it appears that the parathyroid hormone at least initially does not

rats maintained on low phosphorus diets which develop high rates of intestinal calcium absorption also accumulate large amounts of 1,25-$(OH)_2D_3$ (Tanaka & DeLuca 1973). It seemed possible, therefore that the regulation of intestinal calcium transport by phosphate deprivation might well be through the stimulation of 1,25 $(OH)_2D_3$ synthesis. However, in experiments in which rats were given 1,25-$(OH)_2D_3$ from exogenous sources, it is evident that they still show an elevated intestinal calcium absorption when they are given phosphate deficient diets (see Table 1). Thus the stimulation of intestinal calcium absorption by phosphate deprivation is not solely due to the regulation of 1,25-$(OH)_2D_3$ synthesis, but some other unknown factor or metabolic event must be involved. This has not as yet been determined.

### *Regulation of intestinal absorption by parathyroid hormone, calcitonin and glucocorticoids*

The question of whether there are other hormones that might affect vitamin D metabolism can obviously be raised. Work by Garabedian et al. (1974) has shown that the 1,25-$(OH)_2D_3$ stimulated intestinal calcium transport does not require the presence of parathyroid hormone nor its activity enhanced by the presence of this peptide hormone. Furthermore, work being carried out by others with radioactive parathyroid hormone has shown that the intestine is not a target of parathyroid hormone action and the parathyroid hormone is not bound to that tissue (Zull & Repke 1972, Neuman, unpublished results). It therefore seems clear that the parathyroid hormone does not play a role directly on intestinal calcium transport. As will be shown in a later section, in response to the need for calcium, it is the parathyroid glands which sense the serum calcium concentration and secrete the parathyroid hormone. Parathyroid hormone in some unknown way proceeds to the kidney, where it stimulates the synthesis of 1,25-$(OH)_2D_3$. It seems clear then that the reported effects of parathyroid hormone on intestinal calcium transport are mediated by its role in the stimulation of the synthesis of the active form of vitamin D for that process. Therefore, chronic hypoparathyroidism is probably associated with reduced intestinal calcium absorption and an inappropriate response of the intestine to calcium deprivation (Avioli et al. 1974).

It is not at all certain to what extent calcitonin plays a role in the regulation of intestinal calcium transport. *In vitro* experiments using vascularly perfused intestine have shown that calcitonin does inhibit

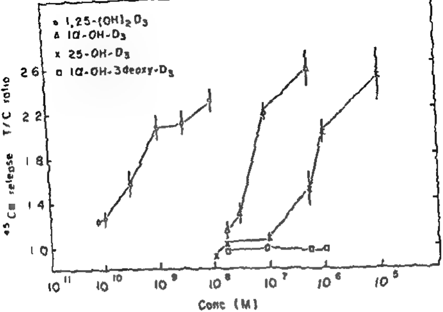


*Figure 6 Resorption of embryonic bone by vitamin D metabolites and analogs in vitro Pregnant rats were given 250 μCi $^{45}$Ca Nineteen day embryonic radii and ulnae from the fetuses were cultured such that one radius served as a control for the other radius from a single embryo To one of these a metabolite at the given concentration was added while the control received the vehicle The ratio of $^{45}$Ca in the medium of experimental bone to that in the control was calculated and plotted (Stern Tanaka DeLuca and Schnoes unpublished results)*

bone in culture has not been closely studied It is of some interest that *in culture* the 1,25-(OH)$_2$D$_3$ and the parathyroid hormone will initiate the mobilization of calcium independent of each other On the other hand *in vivo* it is well known that physiologic doses of either 1,25-(OH)$_2$D$_3$ or parathyroid hormone are required for this system to operate (DeLuca 1974 Rasmussen et al 1963, Harrison et al 1958) In the absence of either 1,25-(OH)$_2$D$_3$ or the parathyroid hormone, mobilization of calcium from bone is markedly diminished The two agents, therefore seem to operate in concert and the absence of either interferes with the process The discrepancy between the results *in vivo* and those obtained *in vitro* are, therefore, of some concern However, *in vitro* the mobilization of calcium is carried out in low phosphate medium It may be that if the culture experiments are carried out at phosphate concentrations approaching normal, both agents must be present to elicit mobilization of calcium from bone

require this mechanism to initiate mobilization of calcium from bone (Rasmussen et al 1964) Although it seems clear that the parathyroid hormone stimulates osteoblast resorption, there is also evidence that resorption of bone takes place by osteocytes and also possibly by osteoblasts in response to this hormone (Belanger 1965) There is some evidence that this hormone stimulates mobilization of calcium from bone via activation of adenyl cyclase and the cyclic AMP mechanism (Wells & Lloyd 1967, Chase & Aurbach 1967) Although the parathyroid hormone is believed to function in the kidney in this fashion the evidence in the bone is not as clear The most likely possibility is that the parathyroid hormone in some way stimulates a calcium transport system which does not involve the synthesis of new protein

*Role of vitamin D*

Another equally if not more important agent in the mobilization of calcium from bone is vitamin D and its metabolites Carlsson and coworkers demonstrated quite early that vitamin D, even at physiologic doses, induces the mobilization of calcium from previously formed bone (Carlsson 1952) This has been confirmed by Nicolaysen & Eeg Larsen (1956) and by work carried out in our laboratory (Blunt et al 1968) It is now clear that it is not vitamin D itself, but rather its active metabolite, 1,25-$(OH)_2D_3$, which brings about this mobilization (Holick et al 1972, Reynolds et al 1973, Raisz et al 1972) The mobilization of calcium from bone in response to 1,25-$(OH)_2D_3$ is blocked entirely by the previous administration of actinomycin D, whereas if that antibiotic is given after the 1,25-$(OH)_2D_3$, the process is not inhibited (Tanaka & DeLuca 1971) It seems that there is more evidence to support the idea that in this system 1,25-$(OH)_2D_3$ may well initiate the process by stimulating the synthesis of specific messenger and specific proteins involved in the transport process Work by Weber et al (1971) has demonstrated that the bone may well accumulate 1,25-$(OH)_2D_3$ in the nucleus of the cells, which would be in support of such a mechanism

The mobilization of calcium from bone has also been studied *in vitro* using isolated bone cultures by both Raisz et al (1972) and Reynolds et al (1973) In this system vitamin $D_3$ itself is totally inactive, whereas 25-OH-$D_3$ functions at concentrations of the order of $10^{-7}$ M (*Figure* 6) (Stern, DeLuca, Tanaka and Schnoes, unpublished results) However, 1,25-$(OH)_2D_3$ is the most potent form functioning as low as $10^{-10}$ M The mechanism whereby 1,25-$(OH)_2D_3$ initaites the mobilization of

The renal reabsorption of phosphate in response to parathyroid hormone has been thoroughly studied and should be briefly mentioned here. The parathyroid hormone inhibits phosphate reabsorption as one of its well known and basic mechanisms. Recent results from two laboratories independently have shown that possibly this inhibition of renal reabsorption of phosphate may well be due to parathyroid induced change in intralumenal pH, rendering the phosphate more ionized and less able to penetrate the renal cells (Bank et al. 1974, Ichikawa & Borle 1974). This exciting new development might well signal a new era in our understanding of parathyroid hormone regulation of renal reabsorption of phosphate.

It is well known that the parathyroid hormone in carrying out its effects in the kidney activates the adenyl cyclase to produce cyclic AMP (Chase & Aurbach 1967). It is not clear whether all of the effects of the parathyroid hormone are the direct result of cyclic AMP or whether the parathyroid hormone activates calcium movement at the same time that it activates cyclic AMP. The action of cyclic AMP appears to require calcium. Again the cellular events and molecular events of the parathyroid hormone induced changes in the kidney have not been thoroughly studied. In any case, the kidney must be regarded as a major organ involved in the regulation of serum calcium and in fact is thought by many to be the major organ determining serum calcium concentration, a position which probably is extreme.

## CALCIFICATION

Much new information has become available in the area of calcification. Although the mechanism which has been favored for many years, namely the catalyzed crystallization by nucleated collagen fibrils, has not been disproved, there has been, in addition, new evidence which suggests that cells which govern calcification accumulate calcium in vesicles and that the vesicles may be either of mitochondrial origin or independent of mitochondria. The vesicles are supposedly secreted into the matrix area and are involved directly in transporting calcium to the calcification sites (Anderson 1969, Anderson & Reynolds 1973, Slavkin et al. 1972). In fact there may even be hydroxy apatite crystals forming in the vesicles. The vesicles also contain enzymes which may well prepare the collagen surface for mineralization. This important new development in vesicles may also usher in a large number of new considerations regarding the mechanism and regulation of calcification

*Role of calcitonin*

Calcitonin is the only hormone which inhibits the mobilization of calcium from bone This peptide hormone, the structure of which is fully known and which has been synthesized, appears to operate in young mammals to block the mobilization of calcium from bone (Talmage & Munson 1972, Taylor 1972) Talmage and his colleagues have suggested with good evidence that calcitonin actually is a phosphate metabolism hormone in which the hormone stimulates the transfer of phosphate into the bone cells and into the bone fluid inhibiting the flow of calcium to the extracellular fluid (Talmage et al 1972, 1973) This interesting possibility is now under examination and additional information will be necessary to establish it on a firm basis Coupled with these very interesting results are histological examinations of the osteocytes and osteoblasts in which there appears to be a shrinkage following calcitonin administration (Talmage et al 1975) Whatever the mechanism might be, calcitonin can operate in the absence of vitamin D and in the absence of the parathyroid hormone (Morii & DeLuca 1967) Its mechanism also remains to be defined at the cellular and molecular level

## RENAL REABSORPTION

A third and very important site of regulation of calcium in the blood is the kidney It has been estimated that the kidney filters and reabsorbs on the order of 7 g of calcium/day Virtually all of the calcium which is filtered is reabsorbed even in the absence of vitamin D and of parathyroid hormone (Bernstein et al 1963, Gran 1960) However, there is clear evidence that parathyroid hormone does increase the renal reabsorption of calcium and there is some evidence that 1,25-$(OH)_2D_3$ also stimulates reabsorption of calcium (Steele et al 1975) However, the effects of the 1,25-$(OH)_2D_3$ on this parameter have not been thoroughly studied In any case, the existence of a calcium binding protein which appears in response to vitamin D has been demonstrated by Wasserman and his colleagues both by direct measurement and by fluorescent antibody methods (Taylor & Wasserman 1972) Thus although 99 per cent of the filtered calcium is reabsorbed in the absence of these agents it is evident that the remaining 1 per cent is reabsorbed much better when these agents are present Much work remains to be done in this area and in regard to the well known effects of calcium and phosphate on their respective reabsorption mechanisms

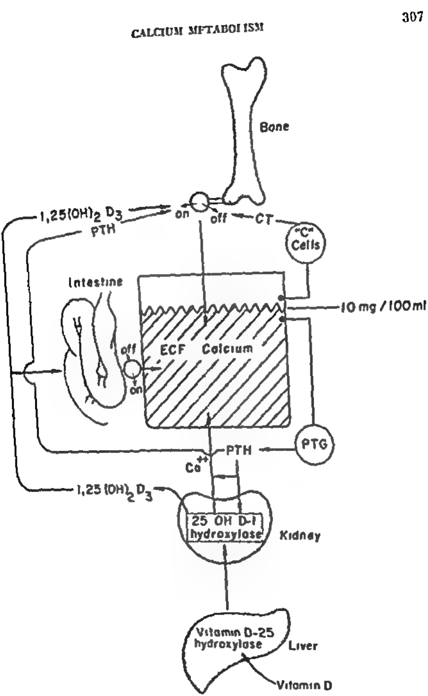


*Figure 7 Diagrammatic representation of the humoral control of serum calcium concentration, taking into account the vitamin D system*

Exactly how calcification is regulated by humoral agents if at all is unknown However, this important mechanism must be considered in any integrated evaluation of calcium metabolism

## CALCIUM HOMEOSTASIS (Figure 7)

Having discussed the sites at which there is humoral regulation of calcium metabolism it seems important now to bring together these various sites in an integrated concept of the regulation of calcium metabolism It is important to realize that there are two cell types which continually monitor serum calcium concentration, namely cells of the parathyroid glands and the c-cells of the thyroid or, in the case of lower organisms, the ultimobranchial bodies In response to hypocalcemia, the parathyroid hormone is secreted This hormone, which is 84 amino acids long, has two basic sites of action The first is the kidney, where it stimulates renal reabsorption of calcium and phosphate diuresis At the same time, however, it stimulates production of 1,25-$(OH)_2D_3$ from 25-OH-$D_3$ (Garabedian et al 1972 Fraser & Kodicek 1973) The parathyroid hormone also goes to bone where together with the secreted 1,25 $(OH)_2D_3$ it functions to mobilize calcium from previously formed bone This then returns calcium to the extracellular fluid The 1,25-$(OH)_2D_3$ which is formed in response to parathyroid hormone, in addition to mobilizing calcium from bone stimulates renal reabsorption of calcium and most important stimulates intestinal calcium absorption This mechanism also restores serum calcium to normal, which then shuts off secretion of parathyroid hormone When the serum calcium rises above the normal level of 10 mg/100 ml, the c cells react by secreting calcitonin Calcitonin in an ill-defined manner proceeds to the bone and blocks mobilization of calcium, thus reducing serum calcium levels It may also proceed to the kidney and to the intestine, where it may also block calcium utilization from the sources, although this is not established Finally phosphate deprivation will stimulate 1,25-$(OH)_2D_3$ synthesis guite independently of any parathyroid hormone (DeLuca 1974) and, in addition phosphate deprivation stimulates mobilization of bone mineral and stimulates intestinal calcium absorption (Baylink et al 1971, Tanaka et al 1972 Morrissey & Wasserman 1971) Thus phosphate deprivation by more than one mechanism will also elevate serum calcium concentration

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## SUMMARY

It is evident that in the past decade much new information has been gathered regarding calcium metabolism at the physiological and extra cellular level In addition new information is becoming available re garding intracellular mechanisms of calcium transport and mobiliza tion Finally, during the past decade the hormone calcitonin has been introduced as well as a hormone derived from vitamin D namely 1,25-(OH)$_2$D$_3$ has been discovered and demonstrated to play a central role in the regulation of calcium metabolism The exciting develop ments will undoubtedly foster the revelation of new information during the next decade which hopefully will bring about an elucidation of the molecular mechanisms of calcium metabolism

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*Key words* calcium vitamin D parathyroid hormone calcitonin 1 25-dihydroxyvitamin $D_3$ phosphorus calcium regulation

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# PROGRESS IN THE USE OF RADIONUCLIDES IN ORTHOPAEDICS

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For more than two centuries the advancement of knowledge in the field of bone physiology has been intimately linked with progress in the use of tracer techniques applied to bone For example use of metal markers by Hales and Duhamel in the eighteenth century put an end to the theory of interstitial elongation and showed that growth occurred by apposition Further refinement of this technique was made possible when roentgenograms were used for *in vivo* localization of metal markers or other landmarks such as growth arrest lines exostoses or striae caused by metal poisoning Use of madder for vital staining of forming bone tissue permitted a detailed description of bone re modelling in experimental animals This technique was of crucial importance to Kolliker in his attempt to link bone cells as seen in the microscope to specific functions in the metabolism of bone Use of lead beta-emitting radionuclides like $^{32}P$ or $^{45}Ca$ and tetracycline increased the sensitivity of the intravital staining techniques compared with madder these tracers provided much higher resolution

Refinement of tracer techniques thus involves localization and quantitation of tracer This can be done conveniently in man only if the tracer can be administered and detected safely *in vivo* without a biopsy These requirements are met by gamma emitting radionuclides Use of radionuclides for the study of skeletal physiology and pathology in man thus constitutes an important link in a chain of events which has its origin in the eighteenth century

In particular the application of radionuclide tracer techniques has provided clinical orthopaedics with an insight into metabolic problems comparable to that which has so long been the prerogative of those studying the parenchymatous organs For example such important conditions in orthopaedics as arthrosis necrosis of bone tumour septic

conditions and rheumatoid arthritis can now be analysed on a clinical level with the aid of tracer techniques In all these conditions, comparison of these metabolic data with information derived from conventional morphologic methods has yielded new insight immediately useful in diagnosis and therapy

On the basis of previous reviews of the use of radionuclides in orthopaedics (Bauer et al 1958, Bauer 1965, 1968, Dreyer & Georgi 1972) five subjects of particular interest will be discussed in this article osteonecrosis, the infected endoprosthesis, functional studies of bone metabolism, choice of tracer, and detection techniques Finally, the present indications for radionuclide scintimetry in clinical orthopaedics will be defined

## OSTEONECROSIS

Cameron (1969) first showed that radionuclide scintimetry may demonstrate an abnormality in non-traumatic necrosis of the head of femur long before morphologic changes are visible by radiography Ahlbäck et al (1968) showed that non-traumatic necrosis of bone is a relatively common condition also in the knee and that radionuclide scintimetry may be of distinct value in the early diagnosis of the condition These findings have subsequently been confirmed by Julien (1974) and others In an extensive study of 70 patients with non traumatic osteonecrosis of the hip and the knee, Julien found agreement between scintimetry/graphy (see below) and the clinical and radiographic development of the disease in all but 3 of 95 involved joints

By current interpretation, high scintimetry values mean a high level of metabolic activity One may then ask why the scintimetry values are high when the bone is dead The resolution of this paradox is that the high metabolic activity is secondary to the primary process, bone death starts a pathophysiologic process characterized by removal of dead bone and formation of new bone The scintimetry values thus reflect the strong tendency to repair, noted by D'Aubigne et al (1965) Immediately at onset, necrosis of bone should thus yield low or normal rather than high scintimetry values To my knowledge, only one patient has thus far been studied at such an early stage of osteonecrosis of the knee, $^{85}$Sr scintimetry was indeed normal One month later, the values were exceedingly high, whereas the typical radiographic lesion did not appear until much later

Recently, similar techniques have been applied to the study of osteonecrosis secondary to intracapsular fracture of the neck of femur (Shoji et al 1972, Asnis et al 1975) Shoji et al showed that the scintimetry values in nine cases of osteonecrosis of the head of femur were remarkably high compared to the values in uncomplicated fracture cases Asnis et al in the same laboratory refined the technique further They demonstrated high accuracy in the prediction of necrosis and/or non union by measurements made 2 months or later after fracture On the basis of these data from the Hospital for Special Surgery in New York it now seems possible to define a new clinical strategy in cases of fracture of the neck of femur Already during the first few months following injury a diagnosis of impending necrosis and/or non union can be made and a hemi- or total arthroplasty performed The dream of predicting these complications already at the time of the initial surgical procedure has not materialized, however Methods based on clearance of tracer injected into the head of femur have proven imprecise, probably because of the difficulties encountered in definition of injection site Methods based on accumulation of tracer have failed, very probably because such methods have now proven to depend on the repair reaction being under way

## THE INFECTED ENDOPROSTHESIS

On the basis of earlier work (Nöh 1972, Groher et al 1972, Venohr et al 1972, Bauer et al 1973), Sjostrand (1974) has made a thorough analysis of radionuclide scintimetry in total hip arthroplasty The purpose of his investigation was to develop a method to be used in differential diagnosis of pain after total hip arthroplasties A base material of 135 hips was divided into three series (1) hips without pain, (2) hips with proven infection and (3) hips with pain but without proven infection Scintimetry was performed ▮ weeks after administration of $^{85}Sr$ The patients were examined by rectilinear scanning over the hips The data were analysed with regard to the acetabulum, the intraarticular space and the proximal femur, and mean values of activity were related to a total body activity index The values thus obtained showed a regular pattern in the uncomplicated arthroplasties, a rapid increase after surgery and then a slow drop to a rather stable plateau some 8 months after surgery Infected hips showed markedly elevated values of either both or one of the components of the endo-

prosthesis. Other causes of abnormally high activity were ectopic bone formation, femoral fracture, non-union of the great trochanter, perforation of the femoral shaft, Paget's disease and osteonecrosis caused by radiotherapy.

By dividing the material into subsets based on clinical and radiographic data, Sjostrand analysed the scintimetry values with regard to causes of loosening of the femoral component. This analysis permitted a description of the varus migration of the femoral component, common and severe in infected cases but not infrequent even in otherwise normal canals. The cause of fracture of the femoral cement could thus be identified in all cases. In infected cases scintimetry permitted identification of the exact location of infections which did not always involve both components of the endoprosthesis. In one case the infected component has subsequently been replaced with the non-infected component left in situ; the outcome is still successful 1 year after the operation. Very probably the scintimetry method may considerably shorten the period of time needed for diagnosis of the so-called infected total hip.

## FUNCTIONAL STUDIES OF BONE METABOLISM

The *development of radionuclide scintimetry of* the skeleton has progressed from (1) topologic identification of abnormality, for example cancer metastases or osteonecrosis of the knee, to (2) interpretation of abnormally high values in the face of a known skeletal abnormality, for example osteonecrosis in fracture of the neck of femur or the infected total hip endoprosthesis, to (3) distinction between different types of development of one and the same condition *It is the third type of application of tracer techniques* that I have denoted as analysis of function. The best example of this third generation type of tracer studies of the skeleton has been furnished by Koshino & Ranawat (1970) who studied $^{85}$Sr scintimetry patterns following high tibial osteotomy for osteonecrosis and/or arthrosis of the knee The purpose of the osteotomy was to shift the body-weight from the diseased medial compartment of the knee to the less involved lateral compartment They found that in those cases where the osteotomy had been mechanically successful, the preoperatively high focus of uptake had shifted laterally However, in those cases that were under-corrected, i e where the osteotomy had not achieved its mechanical purpose, the highest scintimetry values were located medially even

postoperatively These observations are thus a practical example of Wolff's law which relates function, metabolism and form of the skeleton (Bauer 1968)

Further examples of analysis of the function of the skeleton by radionuclide scintimetry have been furnished by Segmüller (1971) and by Muheim (1973) Segmüller thus showed how different types of pseudarthrosis of the lower leg may differ in their scintimetric pattern and that these differences were correlated to the clinical course Muheim found a striking difference in $^{87m}Sr$ uptake in fractures treated conservatively as compared to fractures treated by a compression plate His data furthermore suggested that serial scintimetry may be useful for early detection of incipient non-union

Finally, Muheim & Bohne (1970) have demonstrated that the prognosis in osteonecrosis of the knee as regards development of arthrosis is related to the scintimetry pattern observed during an early stage of the condition

## CHOICE OF RADIONUCLIDE TRACER

Until recently $^{85}Sr$ has been the tracer of choice for radionuclide scintimetry of the skeleton This choice has been based on a thorough knowledge, both clinically and experimentally, of the similarities and differences between strontium and calcium metabolism, on the favourable radiation characteristics of $^{85}Sr$ and on the convenient half-life of $^{85}Sr$ which makes it readily available in the laboratory and permits measurements at the time when the soft tissues have been cleared from tracer However, the long half-life of $^{85}Sr$ raises objections to its use in non malignant conditions in children Therefore a number of short-lived tracers have been tried and some are now well established for routine work Thus, Muheim & Crutchlow (1971) and Asnis et al (1974) have shown that for certain purposes a 1-hour scan with $^{18}F$ may be comparable to a 1- or 2 week scan with $^{85}Sr$ Also $^{87m}Sr$ may be used in a similar fashion as discussed by Charkes (1969) for bone tumour assay and by Staheli et al (1972) in studies of bone and joint infections in children Finally, Subramanian et al (1974), Julien (1974) and several others are at present investigating the possibility of using $^{99m}Tc$ labelled phosphate compounds for clinical bone scintimetry

There is no doubt that the shorter lived tracers may considerably widen the scope of bone scintimetry under clinical conditions As compared to $^{85}Sr$ the shorter lived tracers have the great advantage that

they permit higher activity levels at comparable radiation dose. Even more important is the possibility of doing repeat measurements due to the rapid disappearance of the tracer and the lower radiation dose. The possibility of making measurements immediately after administering the tracer is only an apparent advantage, however, this can be achieved also with $^{85}Sr$.

Even though different tracers may have different advantages and disadvantages when applied to any particular clinical problem, it should be emphasized that each laboratory has to build up considerable experience with each of the tracers used in order to interpret the data properly. For example, the interpretation of the high scintimetry values in osteonecrosis or in the infected hip rests on a firm basis of values recorded in normal cases.

## DETECTION TECHNIQUES

The body of knowledge in radionuclide tracer techniques for the study of bone is based on analysis of digital data. For certain clinical purposes it may be advantageous to display such data in non digital forms, for example by the use of colour (Bauer et al. 1973) or other analogues (Asnis et al. 1973). However, these techniques permit ready translation of the data recorded into precise digital values because the detection devices used in the quoted references have high precisely defined resolution. I have used the term *scintimetry* for these techniques in contrast to *scintigraphy* which denotes measurements made with the aid of a gamma camera and displayed as shades of grey on a photographic film. Even though the gamma camera has reached an admirable level of sophistication when applied to the skeleton it cannot as yet compete with the rectilinear scan performed with a suitably collimated detector. Whereas the camera has been highly successful for the study of parenchymatous organs, the skeleton permits such precise topology, with the aid of radiography, that it pays to develop tracer data of similar precision. This, unfortunately, cannot as yet be made with the gamma camera. The clinician should be aware of this problem. Unless the radionuclide laboratory can furnish him with data performed in optimal fashion, he may well be misled in interpretating tracer data.

## CONCLUSION

The general indications for radionuclide scintimetry in clinical orthopaedic problems are bone and/or joint pain without evidence of radio-

graphic abnormality When applied in this way, scintimetry may aid in the early detection of infection (Staheli 1972), tumour and osteonecrosis When morphologic changes have already occurred, scintimetry may aid in the differential diagnosis of the primary condition, for example vertebral fracture (Defiore et al 1970, Segmuller 1972), or in the early detection of complications, for example necrosis and/or non union in fracture of the femoral neck (Asnis et al 1975) or infection in total hip arthroplasty (Sjostrand 1974) Finally, radionuclide scintimetry may permit a better understanding of the basic properties of bone, to wit the examples given above of the relation between function metabolism and form of the skeleton In this sense radionuclide scintimetry is forming a new bridge between clinical orthopaedics and basic science (Bauer 1968)

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Acta orthop scand 46, 323–328 1975

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# THE FATIGUE OF CARTILAGE IN THE PATHOGENESIS OF OSTEOARTHROSIS

M A R Freeman

There seems no reason to think that osteo-arthrosis represents a single disease entity indeed it should probably be viewed as a condition analogous to heart failure, a pathological process with an approximately unitary end point but numerous aetiologies Only one of these possible aetiologies is discussed here, namely a sequence of events which it is suggested may result in cartilage damage and thereafter in destruction of the joint It will be suggested that this sequence of events may be responsible for osteo-arthrosis in several joints, but in particular that it may be responsible for many examples of so-called idiopathic osteo-arthrosis of the hip

General clinical experience creates the strong impression that many examples of secondary osteo-arthrosis are caused initially by some mechanical abnormality in the joint Thus, for example, persistent talar tilt in the ankle following ligamentous injuries may cause osteo-arthrosis in the ankle, meniscectomy, which is known to increase the contact pressures on the meniscectomised side of the joint, also increases the chances of osteo-arthrosis developing in that side of the joint incongruity at the hip either acquired during childhood or of congenital origin may similarly be presumed to increase the contact pressures by reducing the contact area in the hip, and such incongruous hips are known to be more liable to develop osteo-arthrosis than is a normal hip In the upper limb, osteo-arthrosis in the elbow is rare but occurs as an occupational disease in pneumatic drill operators who sustain multiple blows to their elbows It seems, therefore, reasonable to suppose that there might be a mechanical factor at work in the genesis of idiopathic osteo-arthrosis of the hip Since idiopathic osteo-arthrosis is more common in the hip than in other joints, at least in

Caucasian man, this unknown mechanical factor might be thought to operate particularly in the hip as against other joints Idiopathic osteo-arthrosis is also clearly age-related, being more frequent with advancing years. Thus it might be supposed that there is an age-related change affecting all joints and that this combines with some factor present in certain Caucasian hips to produce idiopathic osteo-arthrosis in that joint.

Mechanically, two tissue elements cooperate to produce the mechanical properties of articular cartilage: collagen and proteoglycan with its retained water. The collagen network confers tensile strength and stiffness upon articular cartilage and retains the proteoglycan gel by trapping it within the collagen meshwork. Finally, the collagen bonds the cartilage to the bone. Proteoglycan complexes appear to be trapped because they are of such a size that they are unable to move through the collagen network, but the possibility that they are bonded to collagen in some more direct way still remains open. The proteoglycans are strongly hydrophilic and therefore tend to draw water into the cartilage matrix. Direct measurements suggest that this pressure is of the order of 3½ atmospheres (Maroudas 1975). Cartilage does not, of course, expand when immersed, because the tendency to swell is resisted by the collagen network within which tensile stresses must be presumed to develop Thus, unloaded cartilage consists of an hydraulically pressurized proteoglycan gel trapped within a collagen meshwork which is pre-stressed in tension Thus, broadly speaking, the compressive properties of articular cartilage are proportional to the amount of proteoglycan in the matrix, whilst the tensile properties are proportional to the structure (as well as to the actual amount) of collagen

It has been known for many years that the matrix of fibrillated cartilage is proteoglycan-depleted and it has therefore been thought that one possible cause of osteo-arthrosis might be proteoglycan depletion due to some cellular abnormality, followed by softening of the matrix and fibrillation With methods of proteoglycan analysis which permit estimations to be made on small pieces of tissue (rather than on bulked areas of the matrix), it is now known that in fact proteoglycan depletion rarely if ever precedes fibrillation (Maroudas et al 1973) If proteoglycan depletion does not precede fibrillation it seems unlikely that it causes it The alternative possibility has to be considered, namely that some other factor acts upon articular cartilage to produce both fibrillation and proteoglycan depletion simultaneously

The tensile properties of human adult articular cartilage have been

extensively studied in my laboratory by Kempson and co-workers Kempson (1973) has shown that the tensile properties vary from the surface through the deeper layers and that this variation can be correlated with the variation in the collagenous composition of cartilage Kempson has also shown that in the surface the tensile properties are strongly directional, and once again this can be explained as being due to the orientation of collagen in the surface The tensile properties appear to vary from joint to joint and from one site to another in the same joint Thus before the effect of, for example, fibrillation or ageing can be related to the tensile properties of the cartilage, it is necessary to ensure that the variables mentioned above have been controlled in any comparison When these variables are so controlled, a change can be demonstrated in the tensile strength and stiffness of articular cartilage with increasing age, at least in the knee (Kempson 1974) This change takes the form of diminishing strength and diminishing stiffness as age advances Since osteo-arthrosis and the incidence of fibrillation both increase with increasing age, the question arises can this loss of the normal tensile properties of articular cartilage be related to the genesis of osteoarthrosis?

Cartilage in life is not loaded statically to destruction as was (necessarily) the case in Kempson's experiments on the contrary, it is loaded cyclically and in compression normal to the surface Cyclical loading raises the possibility of fatigue failure, a phenomenon familiar in many areas of engineering Fatigue is the process by which a loaded structure may fail mechanically in the face of a load of a given magnitude applied on numerous occasions, whereas a load of the same magnitude applied on one occasion does not produce failure Since cartilage is loaded cyclically in life it becomes important to establish whether or not cartilage is fatigue prone The possibility that the tissue is fatigue prone is by no means far-fetched in view of the fact that bone is known to be fatigue prone in the laboratory (Swanson et al 1971), in clinical practice (Morris & Blickenstaff 1967), and on the basis of pathological observations (Todd et al 1972) Since bone and cartilage are essentially composed of the same tissue elements, with the addition of hydroxyapatite in the case of bone, it becomes a possibility that cartilage, like bone is fatigue prone

Weightman, also working in my laboratory, has studied the fatigue properties of human adult articular cartilage both in tension and in compression In tension, Weightman has demonstrated firstly, that cartilage is indeed fatigue-prone, and secondly, that the fall in fatigue

resistance with age is so marked that tissue from cadavers of 20 year olds would not be expected to fail after the application of 100 million cycles at a stress of 5 $MN/m^2$, whereas this stress would produce failure in the tissue of cadavers 50 years of age after application of the order of 10 million cycles (Weightman 1975) Although the tensile stresses occurring in articular cartilage in life are unknown, stresses of this order of magnitude seem likely to occur at least in certain hips

Weightman has also studied the effects upon cartilage of a cyclically applied compressive load (Weightman et al 1973) This experiment does not give a sharply defined end point and therefore does not permit a quantitative result to be obtained It was, however, demonstrated that a cyclically-applied compressive load produces fragmentation of the surface of the loaded cartilage, an appearance similar to fibrillation

It is now suggested that fibrillation and hence osteoarthrosis may be due to fatigue failure in the collagen network of articular cartilage and that the reason why this condition becomes more frequent with increasing age is perhaps partly that the passage of time permits the application of a large number of loads to cartilage but that also, perhaps more importantly, the fatigue resistance diminishes sharply with age in a fashion which cannot be entirely explained as being due to the previous loading history of the tissue There remains the question what is the factor in some apparently normal hips which may be responsible for the genesis of fibrillation and hence of osteoarthrosis in Caucasian man?

In an attempt to answer this question, Day, Swanson and I have measured the contact pressures in various areas of the human cadaver hip (Day et al 1975) We were able to show that the zenith of the young adult acetabulum frequently fails to make contact, not only at low loads as reported by Bullough et al (1973), but also at loads of up to three times the body weight In contrast, in more elderly hips the whole of the acetabulum makes contact at low loads and also at loads of three times the body weight In a number of hips at all ages an anatomical feature was found in the zenith of the acetabulum which when present and making contact, frequently resulted in the generation of very high contact pressures, i e pressures up to three times the average pressure in the hip as a whole This feature consisted of an area, roughly triangular in shape, of thin fibro cartilage at the zenith of the articular surface of the acetabulum The origin of this feature is unknown but its presence has been commented upon by several workers

In summary, the hypothesis is now advanced that fibrillation, and

hence some cases of osteoarthrosis may be due to fatigue failure in articular cartilage and that this phenomenon is age related because the fatigue resistance of the collagen network in articular cartilage diminishes sharply with increasing age The fall in the tensile stiffness and strength of articular cartilage is compatible with this view and suggests that although the amount of collagen in the matrix of cartilage does not diminish with increasing age nor with the onset of osteoarthrosis the mechanical integrity of the network is nevertheless failing These findings would be compatible with the speculation that although the amount of collagen in the network was unchanged the fibres or the cross links between them were breaking Once the surface has become fragmented and the network which normally retains the proteoglycan has been disrupted proteoglycan depletion may occur by simple leakage as a secondary consequence It is further suggested that the reason why this process develops with such frequency in certain Caucasian hips is that these hips contain an anatomical feature namely a thin area of fibrocartilage at the zenith of the acetabulum which is responsible for the generation of very high contact stresses in some joints

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# ARTHROSIS NEW DIAGNOSTIC PROCEDURES

P Ficat & J Arlet

The name arthrosis includes several affections of different aetiology which have only one thing in common a destructive lesion of the cartilage accompanied by structural alterations in the bone

The diagnosis of arthrosis is based above all on radiological signs considered to be characteristic of the disease narrowing of the joint line osteophytes osseous sclerosis and cysts

Unfortunately these signs already represent an advanced step in the disease where the debut as a rule, has been characterized by a clinical period of articular pain without radiological signs which corresponds to an initial localized lesion in the cartilage (the pre radiological stage of the arthrosis)

In order to permit the physician to make an early diagnosis in this stage of the chondrosis we propose two new methods based on comparisons of several parameters namely

1 An anatomic functional exploration of the cartilage which permits us to establish an early diagnosis

2 A vascular and functional exploration of the bone which permits us to begin to narrow down the diagnosis of primary arthrosis

## METHODS

1 *The anatomic-functional exploration of the cartilage* focusses on the tissue itself and includes

*A comparative study of the joint space on radiographs* in standard views and in arthrography in order to estimate the real thickness of the cartilage in the position of function as well as the surface of the cartilage

A macroscopic study of the cartilage surface in arthrotomy (or in arthroscopy) to determine whether it is intact or fissured the consistency is evaluated by palpation

The biopsy through the whole width of the cartilage and the subchondral bone which will be examined by light microscopy and by electron microscopy

The biochemical study the amount of glycosaminoglycans etc

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Figure 3 Specimen of core biopsy of the cartilage with its subchondral bone held by forceps On the left the cartilage measured 17 mm on the photograph on the right the same specimen compressed by forceps measured only 8 mm This explains the flattening of the softened area on the patella in vivo as seen in contrast arthrography

Figure 4 Contrast view of a fissured chondromalacia We can see three fissures clearly and the central one in the middle of the lateral facet goes through the cartilage to the bone The joint space is normal on the standard view

ing the stage of closed chondromalacia is made possible by the technique of skyline view arthrography (Figure 1)

Although the patient presents a painful patellar syndrome initially there is only a localized softening of the cartilage with a macroscopically intact surface and a practically normal X ray (Figures 2 3)

The biopsy of these lesions shows the first signs of degeneration in the cartilage, i e ultramicroscopic structural changes of the three elements of the cartilage

Degenerated chondrocytes

Fragmented and dislocated collagen fibres of unequal length

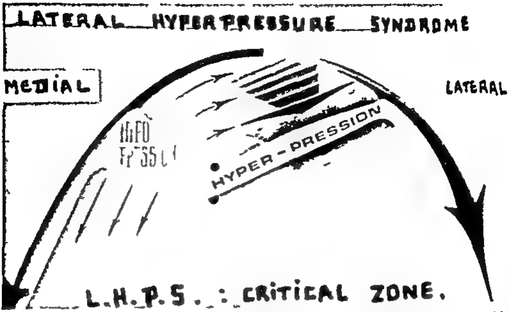


*Figure 1 Lateral hyperpressure syndrome with lateral tilt of the patella induced by hypertension of the thickened lateral retinaculum*

*Figure 2 Narrowing of the patellar cartilage in the critical zone (whereas the joint space on the standard skyline view seems to be normal) This is due to the softening of the cartilage depressed by the articular pressure in vivo as shown in Figure 3*

*Results of exploring the cartilage*

The anatomic functional exploration of the cartilage was made in the patella in cases of chondromalacia and femoro patellar arthrosis and in particular in 180 cases with the lateral hyperpressure syndrome where the aetiology is carefully defined the mechanism is distinct (hyperpressure) and a very early diagnosis dur

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*Figure 5 Contrast view showing an ulceration of the cartilage on the lateral facet The contrast substance reaches the bone, we can see sclerosis of the subchondral bone in the same region The joint space is normal on the standard view*

– Oedematous ground substance due to imbibition of water and loss of glycos aminoglycans

The difference between the thickness of the cartilage measured by arthrography (*in vivo* and under pressure) and the thickness of the biopsy is proportional to the degree of softening and the loss of elasticity Sectioning the lateral retinaculum which leads to lessened articular tension in cases of hyperpressure, represents an effective therapeutic measure

2 *The functional exploration of the bone* is concerned mainly with the intra osseous circulation and comprises

– *A haemodynamic part* with

a) Measurement of the basic intramedullary pressure after [illegible] minutes of waiting normally $\leq$ 30 mmHg and after provoked hyperpressure test (augmentation less than 10 mmHg 5 minutes after injection of 5 ml of physiologic saline)

b) *Intraosseous phlebography* to determine venous drainage absence of stasis and reflux

– *A histopathological part* with

a) Drill biopsy of the bone in the metaphysis epiphysis to determine the effects on the tissues of the impaired circulation

b) Additional analyses oxymetry, bone blood flow strontium temperature

### *Results of bone analyses*

We will here limit the application to the cases of coxarthrosis *The haemodynamic exploration* often shows abnormal values in the cases of established coxarthrosis but the vascular changes seem maximal in primary coxarthrosis

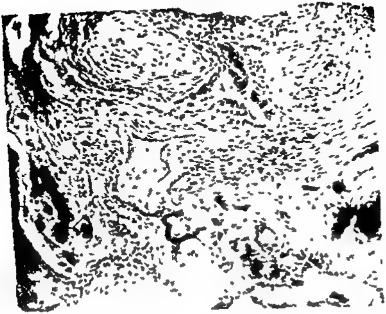

*Figure 6 Marrow of arthrosic type Fibrosis new bone formation foci of stasis*

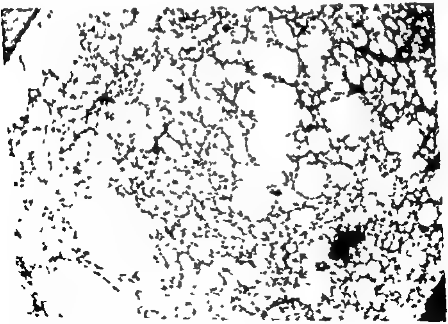

*Figure 7 Marrow of necrotic type with fragmentation of the adipose cells contrasting with cystlike appearance of confluent other cells*

*Figure 8 Marrow of necrotic type Medullary necrosis of reticular eosinophilic type along the total length of the specimen*

Syndrome of stasis and ischaemia

| | | |
|---|---|---|
| Basic intramedullary pressure | | > 30 mmHg |
| Provoked hyperpressure test | | > 10 mmHg |
| Phlebography | absence of one or more efferent veins | |
| | reflux to the diaphysis | |
| | stasis in the metaphysis | |

On the other hand *the histopathologic examination* of the bone marrow obtained by drill biopsy and especially of the marrow under the areas of sclerosis and eburnation shows two groups of lesions

1 *Arthrosic marrow* with scattered areas of stasis and oedema medullary fibrosis chondroid islands thickening of the trabeculae small isolated patches of necrosis near the surface (type 1) but no widespread necrosis (Figure 6)

This group then shows impaired circulation (positive haemodynamic tests) but no necrosis of the marrow It is the group of true coxarthrosis (secondary post dysplastic coxarthrosis and some primary coxarthrosis) where the primary and predominant affection is in the cartilage Only in late stages does one find secondary changes of the bone as a reaction to the altered biomechanics resulting from the changes in the cartilage

2 *Marrow of necrotic type* in this second group there is also stasis and oedema (type 1) In addition one finds a diffuse medullary necrosis sometimes extending throughout the whole drill biopsy of predominantly reticular eosinophilic (type 2)

*Figure 9 Ischaemic coxopathy without dysplasia. Slight narrowing of the supero-medial joint line Cyst of the head inside a sclerotic area No osteophytosis Intra medullar pressure at 65 mmHg in the head Biopsy total necrosis of the bone and marrow*

ccasional trabecular necrosis (type 3) and the appearance of newly formed bone type 4) This is the group that corresponds to the *primary coxarthrosis* of a partic ular kind (Figures 7 and 8)

a *Clinically*

Late age of onset (after 50 years of age)

Often acute

Pseudoradicular pain at night when coughing radiating to an area below the knee

Limitation of movements occasionally paradoxical

Major haemodynamic syndrome especially at the level of the caput femoris

b *Radiologically* (Figure 9)

A uniform or supero internal narrowing of the joint line few or no osteophytes and a dense or occasionally decalcified bone structure

c *Histologically*

The medullary structure is identical to that of osteonecrosis The diffusion and the extension of this necrosis suggest that the marrow is affected primitively and predominantly restricting the degeneration of the cartilage to a lesion of secondary importance The coxarthrosis could really be said to be the consequence of disturbed intra osseous circulation which inevitably must be associated with the osteonecrosis

What speaks in favour of primitive circulatory trouble is that the same lesions are observed in "arthrosis incipiens" with slight and partial narrowing of the joint line without osteophytes and without remodeling of the bone structure and in stage 3 in osteonecrosis except for the narrowing of the joint line in the latter

The contrast between a very small local lesion in the cartilage and an extensive

*Figure 8 Marrow of necrotic type Medullary necrosis of reticular eosinophilic type along the total length of the specimen*

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The contrast between a very small local lesion in the cartilage and an extensive

massive lesion in the marrow suggests that the degeneration of the cartilage is secondary to the circulatory trouble

The prophylactic effect of the intraosseous drilling may influence the evolution of the disease

## CONCLUSION

Two main conclusions can be drawn from this work, one concerning the early diagnosis of arthrosis and the other its aetiology

1 Diagnosis has been made easier by two new methods

a) *Arthrography* permits the discovery of chondromalacia of the patella in a very early stage of localized softening as yet unaccompanied by fissures in the surface or X-ray changes detectable by standard techniques This is done by comparing skyline-views taken at 30, 60 and 90 degrees of flexion in the knee joint

Microscopic studies at this stage have shown changes in the three constituents of the cartilage

We find no better word than chondrosis to describe this state

b) *The functional exploration* of the bone has brought about an important modification of the haemodynamic and anatomo-pathological parameters in certain cases of coxarthrosis consisting of an ischaemia of the sub chondral bone which can be demonstrated at an early stage of localized narrowing of a joint line

2 *The nosological entity* which we recognize as arthrosis must be sub-divided in view of these new discoveries Apart from post-traumatic arthrosis, one can distinguish two forms of cartilage degeneration which are by far the most frequent

a) *One of mechanical origin,* observed in the patella and in dysplastic hips and which is mainly the effect of incongruence and hyperpressure

b) *The other of vascular origin* which we have described in certain primary cases of coxarthrosis without dysplasia and which is the effect of the vascular disturbance associated with ischaemia (ischaemic coxopathy)

After the mechanical and vascular disturbances have been treated preventive treatment of the arthrosis may be undertaken thanks to the early diagnosis achieved by means of these new medullar and cartilage explorations

## SUMMARY

The authors emphasize two new methods for determining the real state of the cartilage and bone structure These methods permit the earl

diagnosis of arthrosis and necrosis before X ray changes appear and perhaps a better management and prognosis

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*Key words* arthrosis chondromalacia bone circulation functional exploration of cartilage functional exploration of early diagnosis cartilage degeneration

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involving only a part of one chromosome are being described We should be aware of the possibility of these less extensive defects as well as the chromosome anomalies that have been known for the past 10 years or so but a detailed knowledge of this subject is not of great practical value to the orthopaedic surgeon Many foetuses with chromosome anomalies will abort early, and many infants are stillborn or die in the first year of life Chromosomal defects involve large numbers of genes and the damage to the body is usually widespread with mental defect and general disorganisation of development

## UNIFACTORIAL DISORDERS

Unifactorial disorders are caused by mutation of *single* genes Most are rare and less influenced by environmental factors than multiple gene disorders The three patterns of inheritance commonly seen are autosomal dominant, autosomal recessive and X linked recessive inheritance X linked dominant disorders do occur, but infrequently A review of the single gene unifactorial disorders in orthopaedic practice is largely a review of the generalised skeletal dysplasias and malformation syndromes

The *generalised skeletal dysplasias* form a subject of great difficulty because of the rarity of the disorders and the absence of detailed family studies identifying the complete range of anomalous development associated with one gene One has only to think of the various signs and symptoms in osteogenesis imperfecta (bone fragility, blue sclerotics, deafness and so on), some appearing in one member of a family, some in another to realise the problems of assessment Genetic counselling therefore, is often hazardous because of this general ignorance and because of the variable expression particularly of the dominantly inherited disorders It is impossible to cover the whole field so I have chosen four groups of disorders where "new" diagnoses or diagnostic techniques have been established recently

(i) Short limbed dwarfism
(ii) Metaphyseal disorders
(iii) Increased bone density
(iv) Storage diseases

Inevitably there is some overlap betwen them and for details the reader is referred to Carter & Fairbank (1974), Spranger et al (1974), and Maroteaux (1975)

Acta orthop scand 46 338–349 1975

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# A REVIEW OF GENETICS IN ORTHOPAEDICS

RUTH WYNNE-DAVIES

There has been greatly increased interest in inherited and developmental disorders over the past decade, with a huge volume of literature appearing in a variety of journals This review of "genetics in orthopaedics" is taken to mean a review of those disorders occurring in orthopaedic practice which have a known genetic basis

Human genetics is of immense complexity On only one chromosome there are thousands of genes, and in man there are 46 chromosomes On only one gene there are many different sites where mutations, or a change in chemical structure, can occur, perhaps with clinically apparent disease resulting—although it is still not clear why these structural changes should occur

Developmental disorders, in man, whether apparent at birth or only in later years, can result either from adverse genetic or environmental factors, or from a mixture of both If a genetic abnormality is present it must fall into one of three groups

i) Chromosome anomalies (groups of genes)
ii) Unifactorial (single gene) disorders with dominant, recessive or X-linked patterns of inheritance
iii) Multifactorial disorders due to multiple genes together with environmental factors

## CHROMOSOME ANOMALIES

Up to a few years ago it was only possible to arrange man's 23 pairs of chromosomes roughly into groups, according to their size and the position of the centromere However, new fluorescent techniques and radioactive labelling make it possible now to identify individual chromosomes and their specific defects This means that cytogenetic diagnosis is becoming a great deal more accurate and many "new" syndromes

In *pseudo achondroplasia* the body proportions look very similar to classical achondroplasia but the skull is not affected and the disorder is not apparent until 1 or 2 years of age. Radiography makes the diagnosis clear because here epiphyses are irregular and small and the vertebrae are affected being biconvex with a protruding central tongue. The genetics are uncertain; indeed this is probably a heterogeneous group of disorders, some dominant, some recessive.

*Metatrophic dwarfism* presents in infancy with short limbs but in later life platyspondyly and a particularly intractable scoliosis contribute to a short trunk type of dwarfism. As with so many of the short limbed dwarfs the thorax is narrow and respiratory difficulties occur. Inheritance is not yet clear.

*Kniest disease* is the last of the dwarfs with short limbs associated with a generalised skeletal dysplasia to be described. These children have a peculiar face with a depressed nasal bridge and also a short trunk associated with platyspondyly. About half of them have a cleft palate. A characteristic radiological feature are the very broad femoral necks. Inheritance is probably autosomal dominant (or perhaps X linked dominant).

There are several forms of dwarfism in which the shortness is produced by structural defects of the limb bones: *Nievergelt syndrome*, and the *ulno fibular type* (both of dominant inheritance) and mesomelic dwarfism (recessive inheritance).

### (ii) *Metaphyseal disorders*

The rare *metaphyseal dysostosis (Jansen type of dominant inheritance)* with severe dwarfing and hypercalcaemia early in the disease has been known for many years. The *Schmid type of metaphyseal chondrodysplasia* is less severe, affecting mainly the lower limbs and particularly the femoral necks. These individuals are of short stature with normal epiphyses. This disorder of dominant inheritance is to be distinguished from the *McKusick type of metaphyseal chondrodysplasia* of recessive inheritance. Formerly known as the cartilage hair syndrome, these individuals have rather short limbs [illegible]

[illegible] ... are now two [illegible] forms of metaphyseal chondrodysplasia associated with these features (one with *thymolymphopenia* and the other with *pan*

(1) *Short-limbed dwarfism*

In the past, all short-limbed dwarfs were thought to have achondroplasia. It is now known that there are at least 20 or 30 different conditions, some inherited and some not. True, or '*classical achondroplasia*' is characterized by an enlarged vault of the skull, depressed nasal bridge and narrow interpedicular distance of the lumbar vertebrae, this narrowing of the spinal canal leading perhaps to paraplegia in adult life. The nearest condition to it is *hypochondroplasia*, this being rather less severe and lacking the skull abnormality. Both are of dominant inheritance.

There are several forms of short-limbed dwarfs either stillborn or dying in early infancy. In *achondrogenesis* and *thanatophoric dwarfism* the limbs are excessively short. In the *short-rib-polydactyly syndromes*, including *asphyxiating thoracic dystrophy*, there are very short ribs accompanied by pre- or post-axial polydactyly. Death usually occurs from respiratory difficulties, the lungs being too large for the narrow thorax.

The inheritance of thanatophoric dwarfism is unknown, but the other lethal forms are of autosomal recessive inheritance, thus there is a high risk of the parents having another similar child.

Other members of the 'short-limbed dwarfism' group are likely to live until maturity, and many of them present difficult orthopaedic problems. The *Ellis van Creveld* syndrome has been known for several years, and is of autosomal recessive inheritance, with particularly short distal limb segments, post-axial polydactyly and often congenital heart disease. *Diastrophic dwarfism* is also recessively inherited and presents difficulties in treatment due to intractable clubfoot, joint contractures and scoliosis developing in early infancy. Curious associated features are the cystic swellings of the ears in the first few weeks of life, subsequently becoming 'cauliflower' deformities, and the short first metacarpals.

*Chondrodysplasia punctata* (Conradi disease) probably occurs in two forms, dominant and recessive, though the clinical distinction is not always clear. The recessive form is associated with icthyosis and cataracts and is frequently lethal in the first year of life. The less severe, dominant, form is not really an example of short limbed dwarfism, because the limb shortening is likely to be asymmetrical. Both forms of Conradi's disease show punctate calcification or stippling of epiphyses but this radiological sign disappears as the child grows.

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*Table 1 Storage diseases*

| | Inheritance | Enzyme | Age of onset | Acid mucopolysaccharide in urine |
|---|---|---|---|---|
| *Mucopolysaccharidoses* | | | | |
| Hurler syndrome (MPS I H) | Autosomal recessive | Deficient α-L-iduronidase | First few months | Dermatan and heparan sulphate |
| Scheie syndrome (MPS I S) | | " | Later childhood | |
| Hunter syndrome | X-linked recessive | Low sulphoiduronate sulphatase | 6–12 months | " |
| Sanfilippo syndrome | Autosomal recessive | Low N-heparan sulphatase or α-acetyl glucosaminidase | Early childhood | Heparan sulphate |
| Morquio syndrome | | ? | 2–4 years | Keratan |
| Maroteaux-Lamy syndrome | | ? | Early-late childhood | Dermatan (some heparan) |
| *Mucolipidoses* | | | | |
| $GM_1$ gangliosidosis Type I | " | Deficient β-galactosidase | Birth-early infancy | Nil |
| Mucolipidoses I | | ? | Late infancy | |
| II (I-cell disease) | | ? | Early infancy | |
| III | | ? | Over 2 years | |
| *Sphingolipidoses* | | | | |
| Gaucher disease (also *Niemann-Pick* disease, metachromatic *leuco*dystrophy, *Fabry* disease and lactosyl ceramidosis) | | Reduced glucocerebrosidase | Childhood or adulthood | |

*creatic insufficiency and neutropenia,* both of recessive inheritance) So in metaphyseal disorders, look also for white cell and immunity problems

One further disorder affecting the metaphyses needs mention—the *Kozlowski type of spondylometaphyseal dysplasia,* differentiated from the preceding diseases by spinal involvement, where platyspondyly and scoliosis contribute to a short-trunk type of dwarfism (dominant inheritance).

### (iii) *Increased bone density*

*Osteopetrosis* has been recognized for many years There is the *congenital or early onset* type, of recessive inheritance, with severe manifestions, progressive anaemia due to encroachment on the marrow space, cranial nerve palsies and so on The *late-onset* form is often of dominant inheritance and is less severe More recently other 'dense bone' disorders have been described In *pyknodysostosis* there is short stature, Wormian bones, dental anomalies, short clavicles and short terminal phalanges as well as bone fragility Marrow problems do not occur, it is of recessive inheritance *Dysosteosclerosis* (recessive inheritance) is characterized also by bone fragility, dental anomalies and increased density of all bones, however, it is differentiated from osteopetrosis by platyspondyly, absence of marrow complications and a zone of increased translucency just proximal to the metaphyseal area In *sclerosteosis* (recessive inheritance) the main features are increased density of the skull, mandible and to a less extent, the long bones Syndactyly is present, and there is a failure of modelling of the diaphyses

There are various disorders in which hyperostosis principally of the skull occurs, with or without thickening of long bones (*craniometaphyseal dysplasia, craniodiaphyseal dysplasia,* and *frontometaphyseal dysplasia*)

### (iv) *Storage diseases*

The storage diseases are among the inborn errors of metabolism, and we have known of the six mucopolysaccharidoses, including the Hurler and Morquio syndromes, for several years More recently another group, the mucolipidoses, have been described, sharing clinical features of both the mucopolysaccharidoses and the third 'storage' group—the sphingolipidoses (Table 1)

if the parents are normal and have had one child with clubfoot, spina bifida or any member of this group, the probability of a second one being born with the same defect is perhaps 2–5 % If they have already had two children with the defect, or if one of the parents has the same anomaly, then the figures rise steeply to between 10 and 40 % We are all familiar with "clubfoot" families, for example The more there are in a family the more there are likely to be, this being one of the main characteristics of multifactorial inheritance

The main disorders of orthopaedic importance likely to be of multifactorial inheritance are

I VERTEBRAL COLUMN
- Neural tube defects (anencephaly, spina bifida cystica) (Williamson 1965, Carter et al 1968, Carter & Evans 1973)
- Congenital scoliosis with multiple vertebral defects (Wynne-Davies 1975)
- Idiopathic scoliosis (though some cases may be of dominant inheritance) (Cowell et al 1972, Riseborough & Wynne Davies 1973, Wynne-Davies 1973)
- Spondylolisthesis (Wiltse 1962)
- Ankylosing spondylitis (Stecher & Hersch 1955, Blecourt et al 1961, Emery & Lawrence 1967)

II HIP JOINT
- Congenital dislocation of the hip (Record & Edwards 1958, Carter & Wilkinson 1964, Wynne-Davies 1970)
- Perthes disease (Fisher 1972, Gray et al 1972)
- Slipped upper femoral epiphyses (Rennie 1972)

III LIMBS
- Talipes equino varus, calcaneo-valgus and metatarsus varus (Wynne Davies 1965, Ching et al 1969, Chung et al 1969)

In most of these disorders there is nothing new to add to well-established data on genetic and environmental factors There are just two points of particular note

(1) *The neural tube defects and congenital scoliosis* It has been known for many years that spina bifida with meningocoele (with or without hydrocephalus) is aetiologically related to anencephaly, because both types of defect occur in the same families A recent survey from Edinburgh and London by Wynne-Davies (1973 and 1975) has

The skeletal findings in all the mucopolysaccharide disorders and the mucolipidoses are similar, and merely indicate that there is some abnormality of mucopolysaccharide or glycoprotein metabolism. Differential diagnosis of these diseases depends upon clinical information such as age of onset, presence or absence of mental retardation, type of inheritance and the type of acid mucopolysaccharide in the urine—this being absent altogether in the mucolipidoses. Radiographic features shared to a greater or lesser extent by the group are a large skull and shallow sella turcica, broad anterior ends of the ribs with thick clavicles and scapulae, oval-shaped vertebrae with an anterior projection inferiorly (though in Morquio disease platyspondyly is present), a wide iliac flare and dysplasia of the femoral heads. Other bones show irregular modelling, and a pointed base of the metacarpals is quite characteristic. Fibroblast cultures grown from these patients show metachromatic granules on staining with toluidine blue, and it is interesting that cultures grown together from different patients in this same group of diseases will correct each other's metachromasia. In the future it will no doubt be possible to identify each disease by identifying each specific enzyme deficiency. At the present time only one has been discovered, the alpha-L iduronidase deficiency in the Hurler syndrome and also (the same enzyme) in the Scheie syndrome, perhaps due to different mutations of the same gene.

## MULTIFACTORIAL DISORDERS

These are caused by many genes, polygenes, together with the action of environmental factors. The characteristic of this group, firstly, is that the disorders are quite common in the general population—indeed providing a large part of the orthopaedic surgeons' work: clubfoot, congenital dislocation of the hip, spina bifida and so on. Secondly, the risk of recurrence in a family is low. By "common" one means perhaps 1, 2 or 3 per 1,000 births. The genetic element is not strong and the risk of recurrence is typically only about 2–5 %, very much lower than the risks in the unifactorial disorders. In disorders of unifactorial inheritance even single families may give valuable information, but in multifactorial disorders large, carefully planned family surveys are needed before any pattern of inheritance emerges and figures for genetic counselling can be obtained. It is impossible to give accurate figures for recurrence risks, since each family must be considered separately, unlike the single gene disorders, the risks here are variable. In general terms,

if the parents are normal and have had one child with clubfoot, spina bifida or any member of this group, the probability of a second one being born with the same defect is perhaps 2–5 % If they have already had two children with the defect, or if one of the parents has the same anomaly, then the figures rise steeply to between 10 and 40 % We are all familiar with "clubfoot" families, for example The more there are in a family the more there are likely to be, this being one of the main characteristics of multifactorial inheritance

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shown that patients from congenital scoliosis clinics with multiple vertebral defects belong to the same aetiological group, whether or not there is spina bifida occulta or any spinal cord defect All these families have a much increased risk of a subsequent child being born with any one of these defects—anencephaly, spina bifida cystica or multiple vertebral anomalies only

The solitary, isolated defects of one hemivertebra or the limited anterior vertebral body defects associated with kyphoscoliosis appear to be sporadic, non-genetic events, carrying no risk to sibs

(ii) *Ankylosing spondylitis* There have been many family surveys of this condition over the past 25 years and it is well established that increased numbers of relatives of index patients suffer from the same condition, the likelihood being that multiple genes are involved as well as environmental factors Recently, Brewerton et al (1973) reported that a very high proportion (90 %) of patients with ankylosing spondylitis have the HL-A27 antigen This means that individuals who possess the gene for this antigen have an increased probability of developing the disease, compared with the population who do not have HL-A27 The picture is not yet complete, but at least one gene in the system causing ankylosing spondylitis has now been identified

## THE CONTROL OF GENETIC DISEASE AND ANTENATAL DIAGNOSIS

Until fairly recently the only possibility of controlling genetic disease was by giving advice to parents relating to the probability of another child being born with the same defect, leaving to them the decision as to whether or not to have another child This sort of genetic advice is still important, but the need for accuracy is even greater now that ante-natal diagnosis is becoming possible in a number of disorders and selective abortion in the early stages of pregnancy can be considered There is no doubt that there will be a reduced number of children born with serious defects in the immediate future, as a result of new techniques for analysing the amniotic fluid and the mothers' serum in early pregnancy It is possible safely to withdraw some amniotic fluid from about the 15th week of pregnancy, there not being sufficient until this time The fluid itself is of maternal origin (not primarily foetal urine, as has been thought in the past, the proteins in it are nearly all derived from the mother) It is not, therefore, (with one major exception) useful for diagnosing disease in the child However, the cells floating in the

fluid are of foetal origin (desquamated epithelial cells and so on). These can be examined in order to determine the sex of the foetus, any chromosome anomalies, and (after culture) enzyme defects in certain inborn errors of metabolism. Current practice in antenatal diagnosis is at present confined to four groups of disorders.

(i) *Down's syndrome (trisomy 21, mongolism)*. This can be diagnosed in the 14th or 15th week of pregnancy by examing the chromosomes of foetal cells. If trisomy 21 is found, abortion can be offered to the parents. This test is currently in use by many obstetricians for all pregnant women over the age of 35 or 40 years, since the disorder is particularly common amongst older mothers.

(ii) *X-linked recessive disorders*. Diagnosing the sex of a foetus is important in the X-linked recessive disorders. A mother who is a carrier of, for example, haemophilia or Duchenne's muscular dystrophy knows there is a 50 % chance that if she has a son he will have the disease. It may be possible antenatally to detect the affected male, or she could elect to have only daughters (half of whom will also be carriers, but will not themselves be diseased). Conversely, it is also possible that a man with haemophilia could elect to have only sons—who will all be normal as they carry only his Y chromosome, whereas all his daughters would be carriers.

(iii) *Inborn errors of metabolism*. There are a few rare metabolic disorders which can be diagnosed on cultured foetal cells before the 20th week of pregnancy and abortion offered if the foetus is affected. In practice this is a very small part of antenatal diagnosis work at present, and it is only after one such child has been born to parents each carrying a recessive gene, that the family becomes known as a "high risk". Subsequent pregnancies can then be screened and abortion offered if indicated.

This field, however, has great scope for development and it should ultimately be possible, by screening all pregnancies, to eradicate these recessively inherited enzyme disorders.

(iv) *Neural tube defects*. A major addition to the field of possible antenatal diagnoses are the "open" neural tube defects of anencephaly and spina bifida cystica. Here the cerebro-spinal fluid is leaking into the amniotic fluid and large quantities of a "new" protein—"alpha-fetoprotein"—can easily be identified as first descr[illegible]

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[illegible] to identifying this protein in the mother's serum (where

the concentration is about one hundred times less than in amniotic fluid) (Brock et al 1973) The 'closed' spina bifida lesions and multiple vertebral anomalies belong in the same aetiological group but cannot be identified pre natally because there is no leakage of cerebrospinal fluid However, these families are at risk of having subsequent children with an 'open' lesion and they may request investigation

These neural tube and vertebral defects are the commonest of all congenital malformations known to man The discovery of alpha fetoprotein and the possibility that we may, in future be able to diagnose some of these conditions by maternal blood tests, gives a great potential for reducing the numbers of severely deformed children

## SUMMARY

A review of disorders with a known genetic basis which occur in orthopaedic practice is presented Four groups of skeletal dysplasias are briefly described (short limbed dwarfism metaphyseal disorders disorders of increased bone density and the storage diseases) Amongst the multifactorial defects the aetiological relationship of congenital scoliosis with multiple vertebral anomalies to the neural tube defects is noted as well as the high proportion of ankylosing spondylitis patients with HL A27 antigen A summary of current practice in antenatal diagnosis is given, including modern methods of detecting open neural tube defects by estimating alpha fetoprotein

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*Key words* review genetic orthopaedic short limbed dwarfism metaphyseal disorders increased bone density storage diseases vertebral anomalies neural tube defects alpha fetoprotein ante natal diagnosis multifactorial inheritance ankylosing spondylitis HL-A27

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Acta orthop scand 46, 350–355, 1975

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# SOME PAEDIATRIC ASPECTS OF MYELOMENINGOCELE

John Lorber

This review is written from the paediatric point of view and is concerned with:

(1) recent advances in the antenatal detection and the prevention of myelomeningocele,
(2) the changes in incidence and pattern of myelomeningocele,
(3) the selective approach to treatment of the newborn,
(4) the need for selective approach to aggressive orthopaedic policy and practice

## 1 *Prevention of myelomeningocele*

We still do not know the cause or causes of spinal dysraphism but advances made since 1972 promise the eventual elimination of at least the more severe cases *Brock & Sutcliffe* (1972) found that alpha feto protein, which is a normal constituent of foetal serum and of amniotic fluid, is present in excessive quantities in the amniotic fluid when the foetus has an open neural tube defect Fortunately this excess is most marked between the 16th and 18th week of pregnancy, when it is easy to carry out amniocentesis and when it is still easy to terminate pregnancy, if need be, by an intraamniotic injection of prostaglandin $F_2$ Milder and closed cases of myelomeningocele may be missed by this technique, but false positive results have not been seen Subsequently these findings have been confirmed by many groups (Allan et al 1973, Lorber et al 1973, Harris et al 1974, Milunsky et al 1974, Nevin et al 1974, Stewart et al 1975) In Britain it is now routine practice in major units to carry out amniocentesis at 16–18 weeks of pregnancy in high risk cases, that is, when a mother has a child with spinal dysraphism already or where there is a family history in close relatives

The alpha-fetoprotein level also should be determined in amniotic fluid samples obtained for other purposes An abnormal result is followed by termination of pregnancy While this method is of great

value in high risk families, it will prevent the birth of only 5 per cent of all cases of myelomeningocele, because it is not practicable to carry out amniocentesis in all pregnancies

It was therefore necessary to look for more universally applicable techniques It was found that alpha fetoprotein is normally present in maternal serum but is often raised if the foetus has a neural tube defect Even so, as the values are measured in nanograms, its estimation requires a highly sensitive radio-immune assay At present these are done individually in a few research centres, but mass testing techniques are being developed and soon we shall be able to monitor all pregnancies with a simple blood test, probably between the 14th and 18th weeks of pregnancy A positive or doubtful result is followed by amniocentesis to confirm the diagnosis From the relatively few data so far, it appears likely that approximately half the cases of spina bifida could be detected by this method As these will be the more severe cases, the beneficial effects and the major implications for future reduced need for orthopaedic services are evident (Brock et al 1973, 1974 Seller et al 1974, Wald et al 1974)

## 2 *Decreased incidence of myelomeningocele*

Antenatal detection and termination of pregnancy is not the only reason for a decrease in the number of babies born with myelomeningocele The rapidly falling birth rate may well be responsible for a 30 per cent drop, this was the decrease of birth rate in Britain between 1968 and 1973 and the fall is continuing

*Table 1 Spina bifida cystica in Sheffield residents*

| | Liveborn | (treated) | Stillborn |
|---|---|---|---|
| 1968 1970 | 46 | (41) | 7 |
| 1971–1973 | 20 | ( 4) | 10 |

In addition there are other, unknown factors which led to a dramatic decrease of spina bifida births in Sheffield Up to 1968 an average of 18 such infants was born each year Since then, fewer and fewer affected babies have been born by 1973 the number was only [redacted] and in 1974 it seems to have been only 4 (Table 1) Neither the antenatal detection nor the fall in birth rate can account for such a large and consistent drop Whether this will be a future pattern and whether

such a change may occur elsewhere, *too, is not yet apparent* There is little doubt, however, that in future we shall have fewer such infants and their orthopaedic problems will be less complex

### 3 *Selective treatment*

The next major change which affects the orthopaedic case load is the selective approach to the treatment of myelomeningocele During the 1960s practically all infants born with myelomeningocele were treated This world-wide policy was largely the result of the example of the Sheffield school (Sharrard et al 1963), where we treated, without selection, 1191 newborn infants between 1958 and 1969 The 4-year survival rate progressively increased to over 60 per cent in spite of tackling the most severe cases, but the long-term results showed that this increase in survival rate has led to a very poor quality of life in the majority In most cases survival produced such immense personal, family, social, surgical, administrative and financial problems that one had to take stock afresh One had to come to the conclusion that the policy of treating all cases is not ethical and not justified Accordingly *one had to search for criteria at or soon after birth* which would identify those who do not have a chance of an acceptable quality of life At the same time one had to be sure that no infant who had a chance of living with moderate handicaps would be excluded from total modern treatment Finally it was essential to establish such criteria that untreated survivors would not live long, and so produce an even more serious situation than if they had been treated from birth (Lorber 1971)

In other publications I have outlined in detail the long-term results related to various clinical signs which are readily detectable at birth by an expert in this field, without need for elaborate or time consuming investigations (Lorber 1972, 1974 a) I found that if any infant had one or more of the specified adverse clinical signs, then the survival rate was less than 50 per cent and the survivors had such severe multi system defects that none had an acceptable quality of life None could hope to earn their living in competitive employment and none could reasonably hope for marriage and normal family life All would have to depend on charity and life in institutions once their parents were too old or no longer alive to look after them Two thirds of the survivors of this unfavourable group were moderately or severely retarded, but it was the more intelligent who suffered most, especially when they

reached adolescence and understood all that they missed and all the problems that lay ahead of them

These adverse signs which subsequently served as criteria against any form of active treatment are as follows

(1) Large thoraco lumbar or thoraco-lumbo sacral lesions related to vertebral level
(2) Extensive paralysis with a motor level at L3
(3) Kyphosis or scoliosis clinically present at birth
(4) Gross hydrocephalus with a maximal head circumference which exceeds the 90th percentile by at least 2 cm
(5) Other gross congenital malformations e g cyanotic heart disease
(6) Gross cerebral birth injury

In addition social factors have to be taken into account especially in borderline clinically more favourable cases The moderately affected unwanted abandoned infant has a very poor chance for an acceptable quality of life

Finally treatment is contraindicated if a badly handicapped infant develops meningitis in the newborn period following closure of the back or the surgical treatment of hydrocephalus (Lorber 1974 b)

I have not included among the adverse criteria urinary or faecal incontinence although this is a profoundly serious handicap medically and socially If one did include this hardly any spina bifida baby would be treated today

Some orthopaedic surgeons naturally question the validity of excluding infants if the neurological level of their lesion is at L3 and not higher However many such infants lose muscle power above this level in spite of early closure all are incontinent at least half develop ... be at risk of multiple ... shunt therapy

... 1974 ... 50 infants with one or more of these criteria were not treated except by normal nursing care The longest survival was 8 months and half were dead by 1 month None lived to need orthopaedic procedures

Such a policy of selection is now almost universal in Britain and is followed by many countries around the world The impact on orthopaedic case load will become progressively more evident as the years go by

4 At present there are still large numbers who need orthopaedic

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*Key words* myelomeningocele screening for alpha fetoprotein contraindications to treatment

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care, often on a massive scale It is not within my competence to discuss the surgical aspects of orthopaedic care No doubt, many procedures are of great value and a planned series of operations based on neurological principles can often improve the quality of life Nevertheless, there are also many disappointments after initial successes and sometimes the situation is worse after major procedures I would urge therefore that before any series of operations are planned, the whole child should be taken into consideration, especially his intellectual level The success of many operative procedures depends on the patient's intellectual ability and his will to make the most of what the surgeon hoped to achieve It is no use use putting hips back into joint if the child is so retarded that he would never walk even if he had much more muscle power It is harmful and a waste of time to carry out heroic procedures on patients who lack a heroic will to maintain the structural improvement It is also essential to consider the child's emotional background taking him away from his family or school may do him permanent emotional harm and interfere with vital education It is of no use trying to make a child walk who has not the will to struggle slowly with calipers, when he can get on faster and with less effort in a wheelchair It may be immensely harmful to occupy his hands with weightbearing when he so desperately needs the finer hand skills to earn a living Most badly paralysed adolescents will take to their wheelchair whatever we advise and it is important to recognise this I would like to close my paper with an appeal to orthopaedic surgeons to concentrate their energies on the more promising cases however hard it seems A rational, selective approach is likely to benefit those who can truly benefit by your skills, and will save much time and false hope in the others

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those that are severe, can be corrected without operating upon bone Muscle activity needs to be balanced by tendon transfer or by denervation or excision of over-active muscle If deformity still remains after correction by soft tissue release procedures, further correction by osteotomy or excision of bone and cartilage may be needed, even in young children Failure to correct deformity, especially in the foot, is likely to lead to serious secondary consequences in later childhood

Immobilisation or fixation with plaster casts or splints should be kept to a minimum and rarely for longer than 1 month When deformity has been corrected at all joints, a programme of braces and supports combined with physiotherapy can be used to promote ability to walk with the help of suitable appliances

The age of the patient is no bar to performance of corrective surgical procedures, but the ideal age at which surgery on the limbs should be commenced is between the sixth month and the second year of life Between the ages of 2 and 5 years, there may be need for further procedures if deformities recur or alternative deformities develop as a result of modification in muscle activity After the age of 12, final corrective surgery may be needed, for example to correct deformities of the spine or to arthrodese joints in the foot

## SURGICAL PROCEDURES

Almost every patient presents with a different combination of problems of paralysis and deformity In many, multiple operations may be needed to correct deformity at the hip, knee, foot and spine such that the total number of orthopaedic procedures needed during childhood averages about eight procedures and in some children may be as many as sixteen In general correction of the limbs should be made proximo-distally It is impossible to describe all the procedures that may be

un proce-

...eral rotation deformity of the hip is commonly found when there is predominant innervation from the upper lumbar segments with weakness distal to this level The main active muscles are the ilio-psoas and sartorius muscles and the limb tends to lie in flexion, lateral rotation and abduction Flexion deformity of more than 30° requires correction by *release of short flexor structures* and transplantation of the ilio-psoas tendon to the anterior aspect of the greater

Acta orthop scand 46, 356–363, 1975

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# THE ORTHOPAEDIC MANAGEMENT OF SPINA BIFIDA

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The aims of orthopaedic management are to correct deformity and maintain the correction, to obtain the best possible locomotor function, and to prevent or minimise the effects of sensory loss Assessment of deformity and paralysis of the lower limbs and trunk needs to be made as soon as possible after birth, at 3-monthly intervals for the first year of life and at 6-monthly intervals until growth is complete Deformity is often present at birth and may be due to unbalanced muscle action in utero, the effects of posture and intrauterine pressure or congenital maldevelopment, or a combination of any of these Deformity arising after birth is most commonly due to unbalanced muscle action and sometimes to malunion associated with a spontaneous fracture Paralysis is due to congenital aplasia or dysplasia of the spinal cord and its roots or to the effects of infection, traction, pressure from lipomata or cysts or vascular damage The affected muscles may show either normal voluntary activity, voluntary activity with overlying spasticity, autonomous or reflex activity without voluntary control or complete paralysis A correct assessment of muscle activity that is needed to determine appropriate orthopaedic and surgical management requires clinical assessment of muscle activity combined with electrical stimulation of motor nerves and muscles Electromyography can be used but is of secondary value

## PRINCIPLES OF ORTHOPAEDIC MANAGEMENT

Conservative methods to correct deformity are inadvisable, especially in the foot because of sensory loss and the risk of producing pressure ulcers Even if deformity is successfully corrected by conservative means, it is likely to recur if there is persistent muscle imbalance Deformity can be corrected by elongation of short tendons and muscles and, provided it is done before the age of 2 years, most deformities, even

those that are severe, can be corrected without operating upon bone. Muscle activity needs to be balanced by tendon transfer or by denervation or excision of over-active muscle. If deformity still remains after correction by soft tissue release procedures, further correction by osteotomy or excision of bone and cartilage may be needed, even in young children. Failure to correct deformity, especially in the foot, is likely to lead to serious secondary consequences in later childhood.

Immobilisation or fixation with plaster casts or splints should be kept to a minimum and rarely for longer than 1 month. When deformity has been corrected at all joints, a programme of braces and supports combined with physiotherapy can be used to promote ability to walk with the help of suitable appliances.

The age of the patient is no bar to performance of corrective surgical procedures, but the ideal age at which surgery on the limbs should be commenced is between the sixth month and the second year of life. Between the ages of 2 and 5 years, there may be need for further procedures if deformities recur or alternative deformities develop as a result of modification in muscle activity. After the age of 12, final corrective surgery may be needed, for example to correct deformities of the spine or to arthrodese joints in the foot.

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*Hip.* Flexion lateral rotation deformity of the hip is commonly found when there is predominant innervation from the upper lumbar segments with weakness distal to this level. The main active muscles are the ilio-psoas and sartorius muscles and the limb tends to lie in flexion, lateral rotation and abduction. Flexion deformity of more than 30° requires correction by release of short flexor structures and transplantation of the ilio-psoas tendon to the anterior aspect of the greater

trochanter to convert it into a flexor and medial rotator When this has been done, walking is possible with the aid of extensive bracing

Flexion-adduction deformity is often accompanied by dislocation of the hip and is associated with innervation from the upper three or four lumbar segments and paralysis distal to this level It may be present in the child at birth or may develop during the first 2 or 3 years of life

Correction is ideally accomplished at the age of 9 months and in two stages At the first stage, a radical division of tight adductor muscles and tendons should restore a normal range of abduction of 80° Two weeks later, flexion deformity is corrected and the muscle activity balanced by postero-lateral transplantation of the ilio-psoas muscle At the same time, the hip joint can be opened, the dislocation reduced and capsulorraphy performed Provided that an adequate reduction has been obtained, subsequent development of the hip is good Active abduction sufficient to prevent a positive Trendelenburg gait is seldom achieved but, in more than 70 % of patients, walking is possible without bracing at hip level (Sharrard 1964)

If subluxation or dislocation has not been corrected surgically before the age of two, it may be necessary to combine adductor release, open reduction and postero-lateral ilio-psoas transplantation with innominate osteotomy or acetabuloplasty followed, if necessary, by varus intertrochanteric upper femoral osteotomy

*Knee* Deformity at the knee may occur in flexion, extension (*recurvatum*), valgus, varus or rotation Flexion or extension deformity is usually the result of muscle imbalance and varus or valgus deformity is more often secondary to a spontaneous fracture

Flexion deformity is seen most commonly when there is reflex innervation with weakness or complete paralysis of voluntary extension by the quadriceps muscle and spastic activity in the knee flexor muscles More than 20° of fixed flexion deformity requires surgical correction In mild cases elongation of the hamstring muscles alone may be sufficient If deformity is more severe than 20°, it is usually necessary to elongate the short hamstring tendons, to transfer the semitendinosus and biceps tendons to the patella and to correct residual flexion deformity by a supracondylar extension osteotomy with removal of a wedge of bone based anteriorly (Sharrard 1971)

Extension or recurvatum deformity is due to a quadriceps acting strongly in the presence of paralysis of knee flexors with anterior prolapse of the sartorius and gracilis tendons over the medial condyle of the femur Correction can be obtained by elongation of the quadriceps

by V-Y plasty of the quadriceps tendon (Curtis & Fisher 1969), posterior transfer of the sartorius and gracilis tendon insertions at the tibia and transfer of the adductor magnus tendon to the semitendinosus tendon

*Foot* Almost any possible variety of deformity in equinus or calcaneus of the hindfoot or forefoot, varus or valgus of the hindfoot or forefoot and abduction or adduction of the hindfoot or forefoot may occur In all but the most lightly paralysed, the soles of the feet are insensitive and are liable to skin breakdown over points of high pressure There is greater liability to pressure ulceration in the soles of the feet in early adolescence, because increase in the size and weight of the trunk is not matched by growth of the feet It is essential, therefore, that correction to produce a fully plantigrade foot should be obtained in early childhood to avoid this complication in later childhood Only a limited amount of correction can be achieved safely by conservative means such as manipulations and plaster casts Operative treatment can be undertaken at any time between the sixth month and second year of life but, before correction is made, an assessment of activity in the muscles and tendons of the foot must be made, prefarably using electrical stimulation studies

Equinovarus is the commonest deformity in spina bifida and is usually associated with dominant action of the invertors and plantarflexors combined with weakness of the dorsiflexors and evertors Even severe deformities can be corrected by elongation of the tendo calcaneus and the tibialis posterior and long toe flexor tendons combined with division of the medial ligaments and capsules of the ankle and subtaloid joints Muscle balance is restored by lateral transplantation of the tibialis anterior or transplantation of the tibialis posterior through the interosseous membrane to the dorsum and outer side of the foot Adduction of the forefoot may need to be corrected at a second operation by medial and plantar release of the soft tissues, possibly combined with multiple basal osteotomy of the metatarsals or excision of the cuboid In severe or recurrent equinovarus deformity, especially in an older child, talectomy (Menelaus 1971) may be the only solution, an important step in this operation may be removal of the tip of the fibular malleolus to allow the calcaneus to articulate with the lower end of the tibia

Paralytic vertical talus deformity is a less common but important deformity of the foot It is one in which there is equinovalgus of the hindfoot and calcaneo-valgus of the forefoot with dislocation of the talo-navicular joint The dorsiflexor tendons are short, tight, and

trochanter to convert it into a flexor and medial rotator When this has been done, walking is possible with the aid of extensive bracing

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In an early case, further progress of the kyphosis may be able to be prevented by a bone graft. Established deformity of more than 90° requires osteotomy-excision of one or two vertebrae of the lumbar spine (Sharrard & Drennan 1972). Correction is seldom perfect, but ulceration can be prevented and upright posture regained. Because of inability to restore the erector spinae to its function as an extensor of the lumbar spine, recurrence of deformity is not uncommon but seldom becomes severe enough to require a second procedure.

Lordosis and lordoscoliosis tend to develop in children with spina bifida at the age of 10 or 11 years, possibly in association with the preadolescent growth spurt in which the vertebral bodies grow rapidly without a corresponding growth of the absent posterior bony processes. Corrective measures by means of plaster casts, polythene supports or Milwaukee braces are difficult to apply and likely to cause severe pressure sores in the sacral and iliac regions. Correction can be achieved by skull-femoral traction for 4–6 weeks followed by multiple wedge osteotomy and fusion of the thoraco-lumbar spine using Dwyer staples and cable fixation (Baker & Sharrard 1973).

Scoliosis associated with hemivertebra formation is not uncommonly found in association with spina bifida. If rapidly increasing scoliosis develops in early childhood, vertebral body fusion on the convex side of the curve may be sufficient to prevent further progress of the deformity and correction and further fusion can be made in later childhood or early adolescence.

## COMPLICATIONS

The most important complications are those arising as a result of sensory loss. Pressure sores may occur in any area of anaesthetic skin, commonly over areas likely to suffer from pressure or friction over an overlying bony prominence such as the plantar surfaces of the feet or the ischial tuberosities. The child and its parents must be taught to maintain a daily watch on the condition of the skin of the soles of the feet and the ischial areas. Any deformities of the foot must be corrected completely and if necessary further correction obtained in adolescence by triple arthrodesis. Footwear specially made to avoid excessive pressure in any area of the sole of the foot may need to be made and, if the child is in a wheelchair, he needs to be taught to avoid sitting on one area of the ischium or perineum for too long at a time.

Spontaneous fractures are liable to occur in the lower limb bones,

strong, the tibialis posterior is stretched and ineffective, and the intrinsic muscles of the sole of the foot are paralysed Correction (Duckworth & Smith 1974) needs to be made through two incisions Through a dorso-medial incision, the tibialis anterior is divided from the navicular, the toe extensor tendons are elongated, the dorsiflexed forefoot is plantarflexed to reduce the dislocation at the talo-navicular joint and reduction is held by means of a transfixing pin The tibialis anterior tendon is transferred to the neck of the talus Through a postero-lateral incision, valgus deformity at the hindfoot is corrected by a detachment of the peroneus brevis from its insertion, release of the lateral side of the subtaloid joint, elongation of the tendo calcaneus and transplantation of the peroneus brevis behind the ankle to the medial side to be attached to the navicular at the insertion of the tibialis posterior If this operation is done before the eighteenth month of life, a good correction can be obtained but, in an older child, it may be necessary to remove the navicular bone in order to obtain correction

In a limb with complete paralysis below the knee, the foot and ankle tend to fall into valgus Extra-articular subtaloid arthrosis is inadequate, and pantaloid arthrodesis is contra-indicated in an insensitive limb Supra-malleolar tibial osteotomy provides a useful means of correcting the valgus deformity (Sharrard & Webb 1974)

The mildest deformity encountered in spina bifida is that of pes cavus and clawing of the toes associated with intrinsic paresis Deformity of the lesser toes can be corrected without difficulty by transplantation of the long toe flexor to the extensor surface of each toe Deformity of the great toe can be corrected by a tenodesis of the flexor hallucis longus to the proximal phalanx (Smith & Sharrard 1973) combined with elongation of the extensors of the great toe The cavus deformity is corrected by release of any tight plantar structures from the calcaneus and from the medial side of the foot

*Spine* Kyphos deformity of the spine is present at birth in one in twenty myelomeningocoeles If severe kyphosis is present at birth, it may make closure of the spinal lesion difficult or impossible Although closure can be obtained by spinal osteotomy on the first day of life (Sharrard 1968), this procedure is no longer recommended because of the association with severe paralysis and a liability to early mortality In some children, kyphosis at birth is mild but increases during growth Ulceration may develop over the kyphos with difficulty in sitting, increasing paralysis and inability to perform an ileal conduit operation because of compression of the abdominal wall

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Scoliosis associated with hemivertebra formation is not uncommonly found in association with spina bifida If rapidly increasing scoliosis develops in early childhood vertebral body fusion on the convex side of the curve may be sufficient to prevent further progress of the deformity and correction and further fusion can be made in later childhood or early adolescence

## COMPLICATIONS

The most important complications are those arising as a result of sensory loss Pressure sores may occur in any area of anaesthetic skin commonly over areas likely to suffer from pressure or friction over an overlying bony prominence such as the plantar surfaces of the feet or the ischial tuberosities The child and its parents must be taught to maintain a daily watch on the condition of the skin of the soles of the feet and the ischial areas Any deformities of the feet must be corrected completely and if necessary further correction obtained in adolescence by triple arthrodesis Footwear specially made to avoid excessive pressure in any area of the sole of the foot may need to be made and if the child is in a wheelchair he needs to be taught to avoid sitting on one area of the ischium or perineum for too long at a time

Spontaneous fractures are liable to occur in the lower limb bones

strong, the tibialis posterior is stretched and ineffective, and the intrinsic muscles of the sole of the foot are paralysed Correction (Duckworth & Smith 1974) needs to be made through two incisions Through a dorso-medial incision, the tibialis anterior is divided from the navicular, the toe extensor tendons are elongated, the dorsiflexed forefoot is plantarflexed to reduce the dislocation at the talo navicular joint and reduction is held by means of a transfixing pin The tibialis anterior tendon is transferred to the neck of the talus Through a postero-lateral incision, valgus deformity at the hindfoot is corrected by a detachment of the peroneus brevis from its insertion, release of the lateral side of the subtaloid joint, elongation of the tendo calcaneus and transplantation of the peroneus brevis behind the ankle to the medial side to be attached to the navicular at the insertion of the tibialis posterior If this operation is done before the eighteenth month of life, a good correction can be obtained but, in an older child, it may be necessary to remove the navicular bone in order to obtain correction

In a limb with complete paralysis below the knee, the foot and ankle tend to fall into valgus Extra-articular subtaloid arthrosis is inadequate, and pantaloid arthrodesis is contra indicated in an insensitive limb Supra-malleolar tibial osteotomy provides a useful means of correcting the valgus deformity (Sharrard & Webb 1974)

The mildest deformity encountered in spina bifida is that of pes cavus and clawing of the toes associated with intrinsic paresis Deformity of the lesser toes can be corrected without difficulty by transplantation of the long toe flexor to the extensor surface of each toe Deformity of the great toe can be corrected by a tenodesis of the flexor hallucis longus to the proximal phalanx (Smith & Sharrard 1973) combined with elongation of the extensors of the great toe The cavus deformity is corrected by release of any tight plantar structures from the calcaneus and from the medial side of the foot

*Spine* Kyphos deformity of the spine is present at birth in one in twenty myelomeningococles If severe kyphosis is present at birth, it may make closure of the spinal lesion difficult or impossible Although closure can be obtained by spinal osteotomy on the first day of life (Sharrard 1968), this procedure is no longer recommended because of the association with severe paralysis and a liability to early mortality In some children, kyphosis at birth is mild but increases during growth Ulceration may develop over the kyphos with difficulty in sitting increasing paralysis and inability to perform an ileal conduit operation because of compression of the abdominal wall

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Sharrard W J W & Webb J (1974) Supra malleolar wedge osteotomy of the tibia in children with myelomeningocele *J Bone Jt Surg* 56 B 458–461
Smith T W D & Sharrard W J W (1973) Flexor hallucis longus tenodesis a new operation for clawing of the hallux *J Bone Jt Surg* 55 B 879

*Key words* spina bifida orthopaedic management of deformity sensory loss osteomyelitis

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especially in those with more extensive paralysis of the lower limbs The diagnosis is often missed or mis-diagnosed as osteomyelitis There is swelling of part of the limb with increased heat, a mild general pyrexia, raised sedimentation rate and raised white cell count Radiographic examination at first may fail to show the fracture, which is often a fracture-separation of an epiphysis, usually at the lower end of the femur. Fractures are particularly likely to occur after a period of immobilisation in plaster. In treatment, plaster fixation or traction with Thomas splintage should be avoided. The simplest measures to maintain the position of the limb are all that is needed and union occurs rapidly with extensive new bone formation.

## END RESULTS

Provided that a child survives beyond the age of 5 years, he has a very good chance of surviving into adult life. The end-result as regards locomotor ability and general function is directly related to the extent of the paralysis and the success of orthopaedic treatment in preventing deformity, to the state of the kidneys and the success of medical and surgical measures in preventing hydronephrosis and renal destruction, and to the presence of hydrocephalus and the success of measures to control it Provided that correct selection has been made in early life, there can be a reasonable expectation that a child will be able to go into adult life and into suitable and worthwhile employment

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the hip muscles These precautions, although efficient, still need improvement, since statistics continue to show a variable but sometimes significant percentage of avascular necrosis It occurred to us that the preparation technique might be able to be improved on We have to remember at this point what we learned from Somerville In November 1957, he reported a series of 50 dislocations, all of which had been reduced without causing any subsequent avascular necrosis The 50 cases had been prepared for the reduction on a Scott frame, i e by progressive traction and abduction These results increased interest in *progressive abduction* In Paris, Petit quickly adopted this new procedure Prior to his visit to Oxford in 1957, *continuous traction* alone had reduced the rate of avascular necrosis in his patients to 15 per cent After his visit to Somerville, the use of traction abduction and internal rotation allowed him to improve his results drastically At the Paris SICOT Meeting in 1966, he reported about 0 5 per cent avascular necrosis after reduction

Within the past decade we have used progressive traction with abduction and internal rotation on all dislocations in older children, with extremely good results Of 72 dislocations, 17 of which were in children more than 4 years old, we have had only one avascular necrosis, and that was in an 8-year old girl after a difficult open reduction One may therefore assert that post reduction avascular necrosis can be prevented by slow progressive preparation, with traction abduction and internal rotation This preparation seems to help the hip, and its vessels and muscles adapt to the position needed for reduction

We go beyond this and use it to achieve a truly *atraumatic progressive spontaneous reduction* Our concern is to set the hip in such a position that it later allows the spontaneous penetration of the head into the acetabulum This ideal position is situated on an axis called *the reduction axis* (Figure 1 a, b, c), which passes through the mid points of both teardrops on the A P film In order to place the head on that axis one has to use

a) traction in order to position the head in front of the acetabulum,
b) abduction, in order to horizontalize the femoral neck, and
c) internal rotation equal to the anteversion angle

When the hip is perfectly oriented on the axis, traction is abandoned and the position is held in a bilateral spica cast Definite reduction occurs by itself in the cast *This is the phenomenon of head penetration*

Acta orthop scand 46, 364–399, 1975

Institut Calot, Berck, France

# THE TREATMENT OF CONGENITAL DISLOCATION AND SUBLUXATION OF THE HIP IN THE OLDER CHILD

GEORGES MOREL

In the difficult process of choosing among the means available for completing the treatment of a congenital hip dislocation *after the age of walking*, it occurred to us that two major concerns were paramount prevention of post-reduction avascular necrosis, and prevention of residual coxo-femoral dysplasia at the stage of stabilization of the reduction During the past 10 years, the emphasis has been on choosing and perfecting the techniques that appeared to be the best solutions to the problems raised in trying to meet these two goals Our study was based on 72 congenital dislocations, 20 congenital dysplasias and subluxations, and 50 residual dislocations and subluxations which were sequelae of previously treated malformations In each of these categories, this study tries to review the problems, to examine some of the recently proposed solutions, to present our personal experience and finally to formulate more reliable indications

## DISLOCATION AFTER THE AGE OF WALKING

### A *Reduction of dislocation and prevention of avascular necrosis*

The severe failures in the treatment of congenital dislocation of the hip are related to avascular necrosis In fact, avascular necrosis may cause deformity of the femoral head and sometimes hopelessly compromises the results Epiphyseal alterations have occurred as a consequence of reduction Many a study on this topic show the importance of circulatory disturbances of the epiphysis after traction on the posterior circumflex artery and after excessive pressure on the femoral head It seems obvious to us now that any reduction should be attempted only after *preparation by continuous traction* of the relevant lower limb Progressively lowering the femoral head helps the circulatory system to adapt to the new position of the femur and loosens

the hip muscles These precautions, although efficient, still need improvement, since statistics continue to show a variable but sometimes significant percentage of avascular necrosis It occurred to us that the preparation technique might be able to be improved on We have to remember at this point what we learned from Somerville In November 1957, he reported a series of 50 dislocations, all of which had been reduced without causing any subsequent avascular necrosis The 50 cases had been prepared for the reduction on a Scott frame, i e by progressive traction and abduction These results increased interest in *progressive abduction* In Paris, Petit quickly adopted this new procedure Prior to his visit to Oxford in 1957, continuous traction alone had reduced the rate of avascular necrosis in his patients to 15 per cent After his visit to Somerville, the use of traction abduction and internal rotation allowed him to improve his results drastically At the Paris SICOT Meeting in 1966, he reported about 0.5 per cent avascular necrosis after reduction

Within the past decade we have used progressive traction with abduction and internal rotation on all dislocations in older children, with extremely good results Of 72 dislocations, 17 of which were in children more than 4 years old, we have had only one avascular necrosis, and that was in an 8-year-old girl after a difficult open reduction One may therefore assert that post reduction avascular necrosis can be prevented by slow progressive preparation, with traction abduction and internal rotation This preparation seems to help the hip, and its vessels and muscles, adapt to the position needed for reduction

We go beyond this and use it to achieve a truly *atraumatic progressive spontaneous reduction* Our concern is to set the hip in such a position that it later allows the spontaneous penetration of the head into the acetabulum This ideal position is situated on an axis called *the reduction axis"* (*Figure 1 a, b, c*), which passes through the midpoints of both teardrops on the A P film In order to place the head on that axis one has to use

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When the hip is perfectly oriented on the axis, traction is abandoned and the position is held *in a bilateral* spica cast Definite reduction occurs by itself in the cast *Thus is the phenomenon of head penetration*

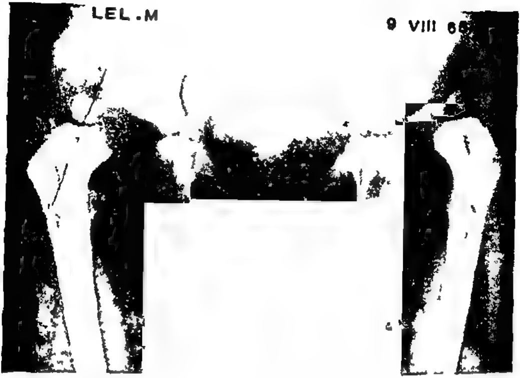


*Figure 1 a Bilateral congenital dislocation in a girl aged 2 years 4 months*

*in the cast* (Figure 2 a, b, c) described by Severin and later by Petit Our experience showed *that progressive spontaneous penetration occurs in most cases when the orientation of the femoral head is kept in the spica* Of 72 dislocations (Table 1), 56 (77 per cent) of the cases were reduced in this way What are the advantages of this technique? 1) It is an atraumatic closed reduction Its safety is obvious, since out of 56 reductions we have not had one single case of avascular necrosis 2) It is efficient, since out of 72 dislocations it allowed a closed reduction in 56 cases, 13 of which were in children more than 4 years of age 3) It permits distinguishing between hips which will respond to closed reduction and those which need an open procedure The criterion is the *absence of penetration of the head* after adequate immobilization in the spica In those cases arthrography almost always shows a narrow pinhead like isthmus There is no way the head can go through it, so open reduction is mandatory However, in order to be efficient, this technique has to be *very precise* Adhesive skin traction is applied on both lower limbs and is carefully padded with bandages In order to keep the limbs under enough tension, the bandages are rerolled every second day While one person removes the traction weights and maintains the limb in position by applying slight traction,

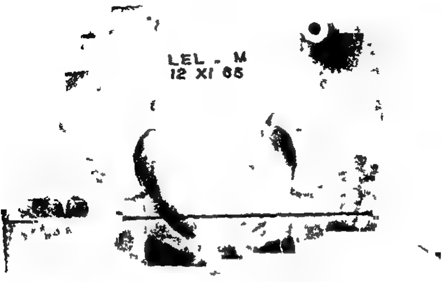


Figure 1 b Setting of the femoral heads on the reduction axis


Figure 1 c Bilateral reduction occurred by itself in the cast

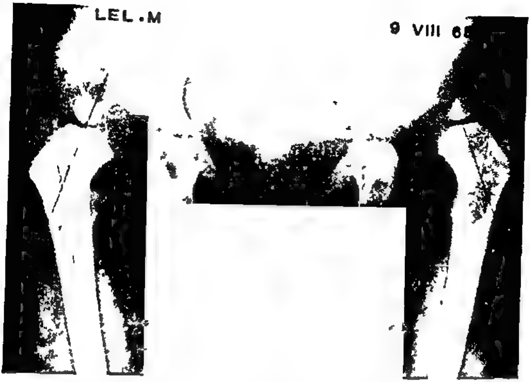


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*Figure 1 b Setting of the femoral heads on "the reduction axis".*


*Figure 1 c. Bilateral reduction occurred by itself in the cast.*


*Figure 2 a, b, c*
*The phenomenon of head penetration studied by arthrography*

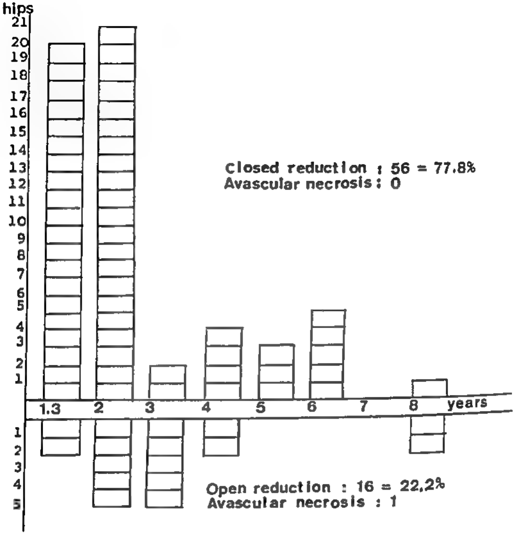
*Figure 2 a Girl, aged 3 years*

*Figure 2 b At the stage of immobilization in the cast*

*Figure 2 c 2 months later*

another person rolls the bandage The bandage has to be tight enough to prevent slipping of the adhesive on the skin, but obviously should not be so tight as to hamper circulation Counter traction is obtained by immobilizing the chest of the child in a canvas brace fastened to the bed and elevating the bottom part of the reduction frame (Figure 3) The three stages in setting the femoral head on the reduction axis are as follows a) *lowering* is performed by longitudinal traction with progressively heavier weights X rays are taken once a week to check the progression of the head Traction force varies and has been adapted to each particular case *For a* 1½ year old child one starts with 0 5 kg ... hird week In ... The lowering ... than 1 month It is therefore a quite *forceful traction but it is progressive* It is stopped when the head is in front of the acetabulum b) *Abduction* This is performed by lateral displacement of the traction pulleys on the *curvilinear* edge of the reduction frame An abduction of 45° to 50° is achieved within 10 days When 25° 30° of abduction are obtained the straps of internal rotation are set in place They are only supposed to counteract the external rotation

*Table 1 Congenital dislocations 72*




in the beginning and later to induce some internal rotation c) *Internal rotation* This is performed by use of a folded strap (Figure 4) applied at the root of the thigh and fastened with a safety pin to the postero lateral aspect of the bandages One of the heads of the folded strap turns around the thigh and must be anchored to the bed in order to fix the rotation and the limb The other head, the most superficial one, supports the weights and allows progressive internal rotation This latter becomes easier when longitudinal traction decreases It is therefore necessary to decrease the traction as needed for the rotation Abduction remains unchanged at this stage Internal rotation reaches progressively the anteversion angle, and will therefore be different for each case One starts with 0 100 kg and reaches progressively 0 500 kg,

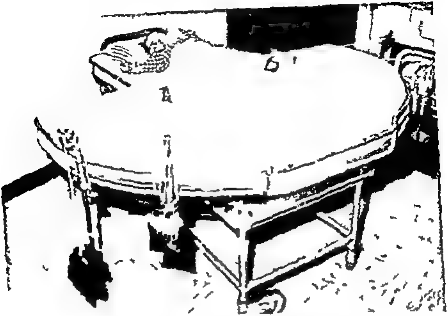
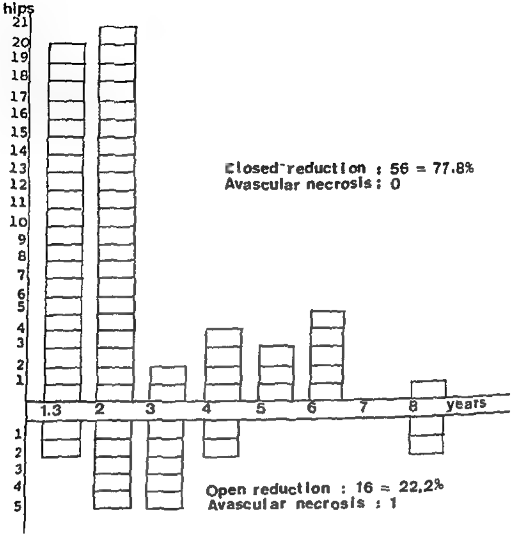


*Figure 3 The reduction frame*

0.750 kg up to 1 kg. It is essential that the three stages are adapted to the child's reactions. No pain should be felt. If the child complains in his sleep or during the day, the sequences are too fast. One then must stop for a day or two, or one may go backwards and decrease the weights or the abduction if necessary. The most difficult part of the treatment is the internal rotation and should be performed very gently. This progressive setting of the head and neck of the femur on the reduction axis is checked on X rays once a week. The minimum time for this phase is 5–6 weeks. In older children or in difficult cases it may take 2 months. When the positioning of the hip is good it is then time to maintain the position in a bilateral spica cast without any reduction manoeuvre. Making the spica is not particularly difficult and is done on a reduction frame in order to prevent any movement. The child is not usually anesthetized but is always sedated. Several assistants are necessary in order to hold the position obtained after traction (Figure 3). *It is essential to keep the femoral heads in the right direction in the cast* if one expects them to penetrate into the acetabulum. Usually we have kept the patients immobilized for a couple of months before checking the reduction. Recently we have actually noticed on tomograms made through the cast that penetration

*Table 1. Congenital dislocations 72*

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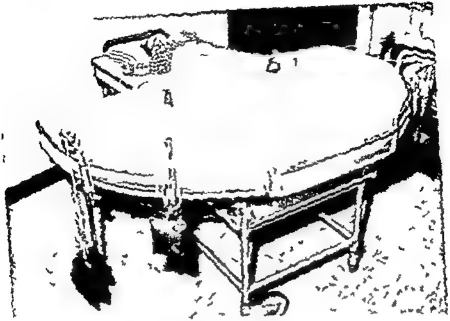

Figure 5 The reduction frame

0.7/0 kg up to 1 kg. It is essential that the three stages are adapted to the child's reactions. No pain should be felt. If the child complains in his sleep or during the day, the sequences are too fast. One then must stop for a day or two, or one may go backwards and decrease the weights or the abduction if necessary. The most difficult part of the treatment is the internal rotation and should be performed very gently. This progressive setting of the head and neck of the femur on the reduction axis is checked on X rays once a week. The minimum time for this phase is 5-6 weeks. In older children or in difficult cases, it may take 2 months. When the positioning of the hip is good, it is then time to maintain the position in a bilateral spica cast without any reduction manoeuvre. Making the spica is not particularly difficult and is done on a reduction frame in order to prevent any movement. The child is not usually anesthetized but is always sedated. Several assistants are necessary in order to hold the position obtained after traction (Figure 5). It is essential to keep the femoral heads in the right direction in the cast, if one expects them to penetrate into the acetabulum. Usually we have kept the patients immobilized for a couple of months before checking the reduction. Recently we have actually noticed on tomograms made through the cast that penetration

*Figure 4 Internal rotation the two heads of the folded strap*

may occur more rapidly. This has allowed us to shorten the immobilization in the cast and go directly to the next step, which is surgical stabilization of the reduction.

## II *Stabilization of the reduction and prevention of residual hip dysplasia*

After the age of walking, the reduction of the dislocation is unstable and in most cases requires surgery. In order to accomplish this in the best way, one has to consider the future of the hip, the risk of osteoarthritis later, and the *prevention of residual hip dysplasia*. As a matter of fact, long term follow-up shows that this dysplasia remains quite frequent after classical treatment, i.e. after femoral osteotomy as advised by Somerville and Pauwels. *The improvement of congruity obtained by varisation derotation osteotomy is unable in most cases to allow normal development of the acetabulum.* This latter remains insufficient and cannot prevent the onset and worsening of late subluxating coxa valga, which compromises the end results of the treatment (Figure 6).

Figure 5 The bilateral spica used for closed reduction

We have therefore considered very carefully the works of those who suggested *direct correction of residual acetabular insufficiency* Pemberton reported a technique of pericapsular osteotomy of the ilium which would allow better covering of the head and stabilization of the reduction and subsequently better development of the acetabulum We have no experience with that kind of operation which appears to be a sophisticated acetabuloplasty Theoretically its disadvantage might be to modify the shape and capacity of the acetabulum In practice it does not seem to be an easy operation Salter on the other hand has designed an operation to correct the maldirection of the acetabulum without altering its integrity Technically this operation is easier and its efficiency has been proven in a large number of cases

Within the past 10 years we have used *the innominate osteotomy of Salter* to stabilize reductions in dislocations in older children The following will show how we have incorporated this procedure into our therapeutic protocol One has to separate closed reductions from the cases which require an open reduction

a) *Closed reduction* When the X ray film shows that the head has penetrated the acetabulum the spica cast is removed under general anesthesia The position of the hip is then checked with a new A P

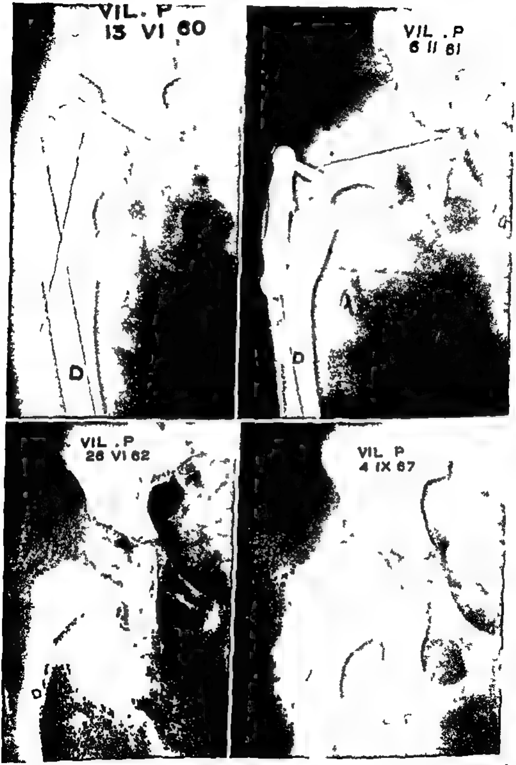


*Figure 5 Boy aged 15 months Open reduction and varisation derotation femoral osteotomy Failure of normal acetabular development and residual subluxation*

*Figure 7 Positioning of the child on the operating table*

film Without modifying abduction one takes an A P film in a free position and then another one in internal rotation equaling the anteversion angle There is no movement of the joint, but the purpose of this is to determine before innominate osteotomy which cases will need a *combined femoral derotation osteotomy* As our experience has shown that excessive anteversions can lead to redislocations, we tend to correct those over 55 60° In the operative theatre the patient is positioned partly on his side, with the lower limb in *abduction internal rotation* (Figure 7) in order to maintain congruity At this stage, on the basis of the preoperative X ray one decides whether to use simple innominate osteotomy or to combine it with a derotation osteotomy In both cases, since reduction has been obtained the whole operation will remain extra articular, so there is never any direct action on the joint itself and its different elements Therefore one may say that from the beginning of traction until the end of the surgical stabilization, the treatment remains atraumatic (Figure 8 a b, c, d, e and Figure 9 a, b c d) From the technical viewpoint, innominate osteotomy was performed as described by Salter but with slight modifications 1) The operative positioning is slightly different 2) There is no arthrotomy since the dislocation is reduced 3) There is no adductor or iliopsoas

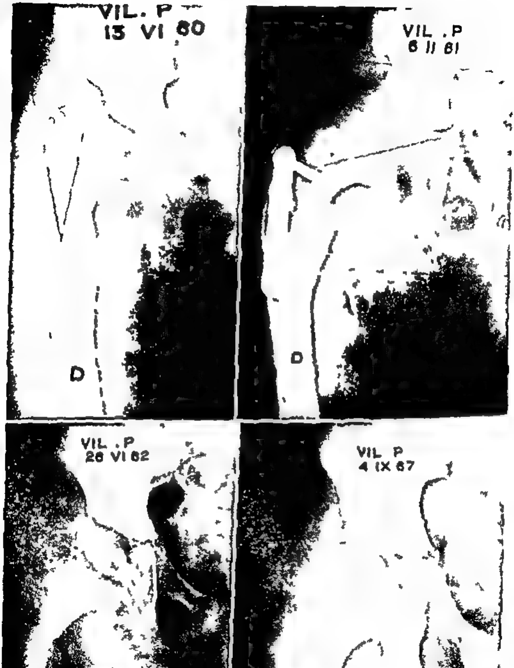


*Figure 8. Boy aged 15 months. Open reduction and varisation derotation femoral osteotomy. Failure of normal acetabular development and residual subluxation.*

*Figure 7 Positioning of the child on the operating table*

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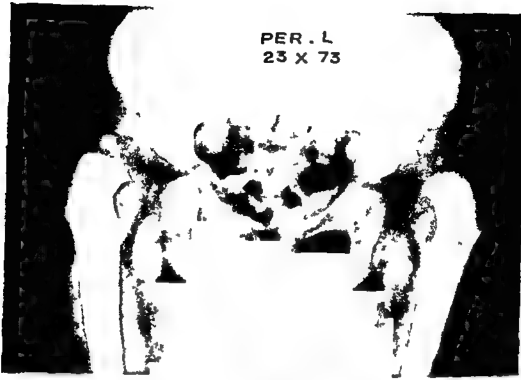


*Figure 8 a Bilateral congenital dislocation in a girl of 17 months*


*Figure 8 b Lowering of the heads by longitudinal traction*


*Figure 8 c Setting of the femoral heads on the reduction axis*

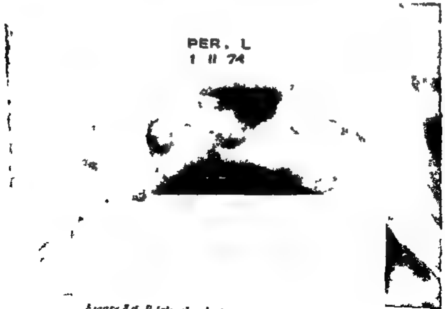


*Figure 8 d Bilateral reduction in the cast (tomogram)*

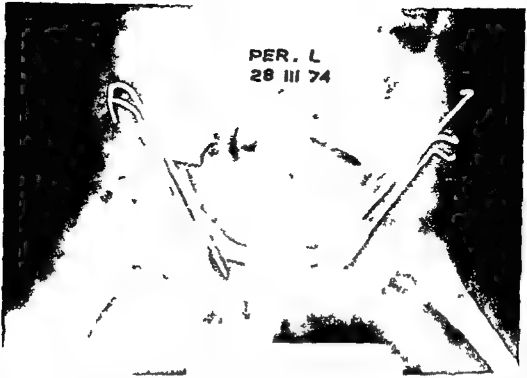


*Figure 8 e Stabilization of the reduction by innominate osteotomy on the left on February 14 1974 and on the right on March 28 1974*

tenotomy since the closed reduction has allowed progressive stretching of these muscles 4) There was no capsulorrhaphy Subsequently we think that it might have improved the stabilization of three hip dislocations which recurred after operation When femoral derotation osteotomy is necessary we perform the two operations on the same day Femoral osteotomy is performed first through a lateral approach over the subtrochanteric area then innominate osteotomy proceeds through the usual approach After surgery the child is immobilized in a bilateral spica after the best positioning of the lower limbs has been ascertained by X rays A couple of months later the wires are removed but the lower limbs remain immobilized for one more month in plaster splints which allow flexion extension with 30° of abduction and moderate internal rotation

b) *Open reduction* If 2 months of being in a plaster cast has not allowed the head to penetrate the acetabulum we proceed with arthrography in order to check the interposition and the nature of the intra articular obstacle We perform the open reduction first *it is very important that the head be perfectly reduced before stabilization* This step is performed with innominate osteotomy either during the same

stage or in a second stage The approaches have to be adapted to the different problems presenting together There are three of them

1) If the head has been lowered and is well directed, if the anteversion is not excessive, we proceed then with Salter's operation Reduction through an anterior approach and stabilization by innominate osteotomy (Figure 10 a, b, c, d)

2) If the head is low enough and the anteversion angle exceeds 55 to 60°, reduction is then performed through a Watson Jones approach allowing also a derotation osteotomy Innominate osteotomy is performed through a second approach either immediately or after 4–6 weeks of plaster immobilization

3) If the head has not been lowered enough in older children or after previous treatments elsewhere, the main concern is the reduction If this latter was performed forcefully, the risk of avascular necrosis would be quite high Our only case of avascular necrosis was in an 8-year-old girl whose reduction had been difficult The solution to this problem has been given by Klisic After referring to Ombredanne's works he showed by his operative successes that the best way to reduce the dislocations, *without dangerous pressure* on the femoral head was to perform a *shortening of the shaft of the femur* We have had experience using his technique for, e g arthrogryposis, cerebral palsy and osteomyelitis sequelae, which have a worse reputation than congenital dislocations The results obtained allow us to state that his technique is, at present, the best solution we found to this problem From the technical viewpoint we perform a Watson-Jones approach with femoral osteotomy under the lesser trochanter As Klisic advises, the psoas tendon is divided and the joint approached on its inferior aspect after reversing the proximal fragment into abduction When the joint has been cleared, reduction of the head into the acetabulum is performed and does not appear to be impeded by the glutei muscles On the contrary, the long muscles of the thigh are overstretched and induce a dangerous pressure on the reduced head The only way to prevent this is to shorten the shaft as needed When femoral osteosynthesis is completed stabilization of the reduction is started at once or is performed as a second stage procedure after plaster immobilization in the most stable position Klisic stabilizes his reduction with a Chiari osteotomy Up to now we have always used the innominate osteotomy

For these difficult cases it occurred to us that we could widen the spectrum of indications by using Steel's "trick" This author obtains

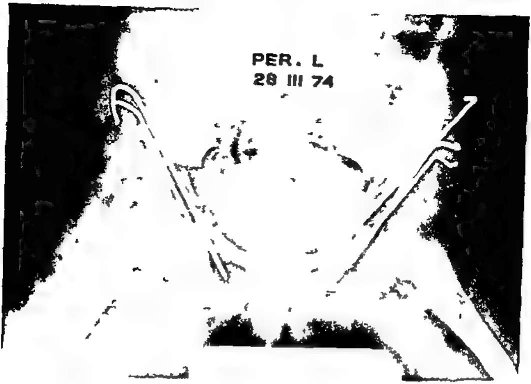


*Figure 8 e Stabilization of the reduction by innominate osteotomy on the left on February 14 1974 and on the right on March 28 1974*

tenotomy since the closed reduction has allowed progressive stretching of these muscles 4) There was no capsulorrhaphy Subsequently, we think that it might have improved the stabilization of three hip dislocations which recurred after operation When femoral derotation osteotomy is necessary, we perform the two operations on the same day Femoral osteotomy is performed first through a lateral approach over the subtrochanteric area, then innominate osteotomy proceeds through the usual approach After surgery, the child is immobilized in a bilateral spica after the best positioning of the lower limbs has been ascertained by X-rays A couple of months later the wires are removed, but the lower limbs remain immobilized for one more month in plaster splints which allow flexion extension with 30° of abduction and moderate internal rotation

b) *Open reduction* If 2 months of being in a plaster cast has not allowed the head to penetrate the acetabulum we proceed with arthrography in order to check the interposition and the nature of the intra-articular obstacle We perform the open reduction first, *it is very important that the head be perfectly reduced before stabilization* This step is performed with innominate osteotomy, either during the same

stage or in a second stage The approaches have to be adapted to the different problems presenting together There are three of them

1) If the head has been lowered and is well directed, if the anteversion is not excessive, we proceed then with Salter's operation Reduction through an anterior approach and stabilization by innominate osteotomy (Figure 10 a, b, c, d)

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*Figure 9 a Congenital dislocation of right hip in girl aged 5 years 7 months and weighing 18 kg Beginning the skin traction on August 9 1974 Weights reached 10 kg*

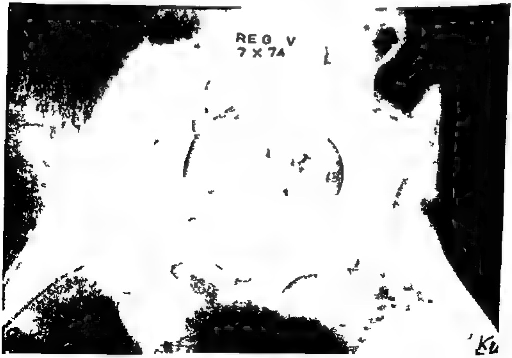


*Figure 9 b Setting of the femoral head on the reduction axis*


*Figure 9 c Reduction in the cast (tomogram)*


*Figure 9 d Stabilisation of the reduction by innominate osteotomy*

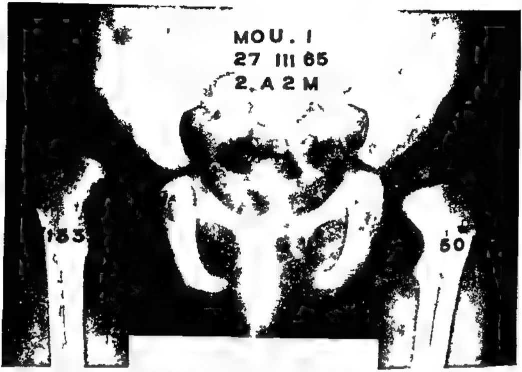


*Figure 10 a Congenital dislocation of the right hip and subluxation of the left hip in girl aged 2 years 2 months*

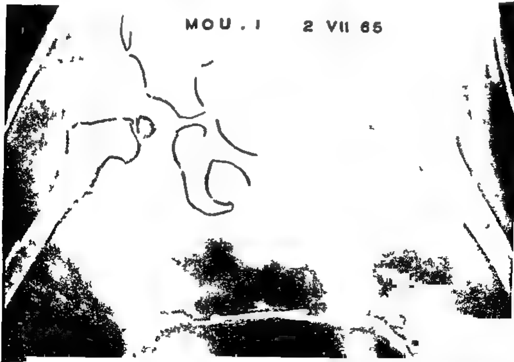


*Figure 10 b Absence of penetration of the head on the right after immobilization in the spica*

*Figure 10c Arthrography shows a narrow pinhead like isthmus*


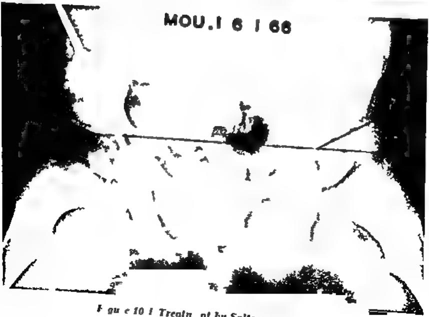


*Figure 10 I Treatment by Salter's operation*

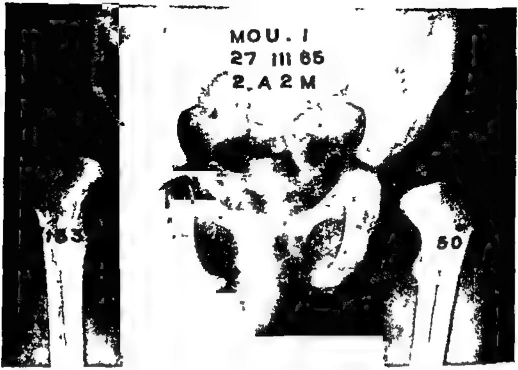


*Figure 10 a Congenital dislocation of the right hip and subluxation of the left hip in girl aged 2 years 2 months*


*Figure 10 ... in the spica*

Figure 10 c Arthrography shows a narrow ... nhead like isthmus


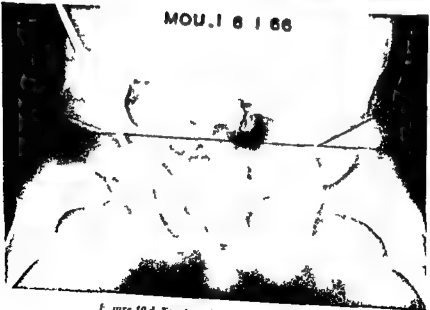


Figure 10 d Treatment by Salter's operation

an easier and more efficient distal fragment tilt by dividing the iliopubic and ischiopubic rami We have used it once and were very pleased with its efficiency

The solutions that we have proposed appear to answer the wide spectrum of possibilities Incoercible and incongruous hips are not indications for Colonna arthroplasty One knows by now that its later results are mediocre or poor, and it pleases us to solve these problems with a different solution

## RESULTS OF CONGENITAL DISLOCATION TREATMENT

These are the results of 72 dislocations The youngest child was 15 months of age, the oldest cases were 8 years old Minimum follow up was 1 year, maximum was 10 years Fifty-two per cent of the cases have been followed- up for at least 5 years Fifty-six dislocations were reduced by closed methods, 16 by open methods All cases were made stable by Salter s innominate osteotomy Additional derotation osteotomy was performed in 15 cases, of which nine were one stage operations and six were two stage procedures Additional varisation derotation osteotomies were done in eight cases, four prior to innominate osteotomy and four subsequently

From the clinical viewpoint one may stress *that closed reductions did not lead to any limitation of the range of motion of the hips,* but some open reductions did

From the roentgenological viewpoint the results were assessed according to Severin's classification as described by Salter In type I the hip is perfect, with a normal CE angle, and this is considered an excellent result In type II, there may be some deformity of the femoral head but a normal CE angle, and this is considered a good result In type II special, there is moderate deformity of the femoral head but a normal CE angle In type III, there is residual dysplasia of the hip but no subluxation however, the CE angle is less than normal Type II special and type III together are considered fair results In type IV, there is some degree of subluxation with the CE angle near zero, and this is considered a poor result In type V, the subluxation is more severe or there is a wandered acetabulum In type VI, there is complete dislocation Both type V and type VI are considered complete failures

Results are presented in Table 2 The group of children under 4 years of age (Figures 11 and 12) with 55 dislocations had excellent


*Figure 11 Congenital dislocation of the right hip in boy aged 1 year 5 months Six and a half years after closed reduction and innominate osteotomy*

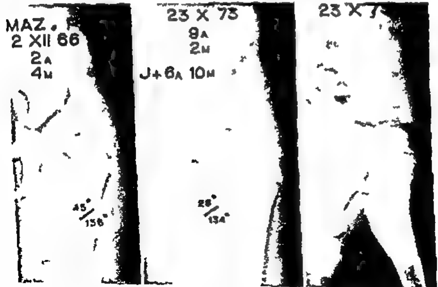


*Figure 12 Congenital dislocation of the left hip in a boy aged 2 years 4 months Six years ten months after closed reduction and innominate osteotomy (the anteversion angle decreased)*

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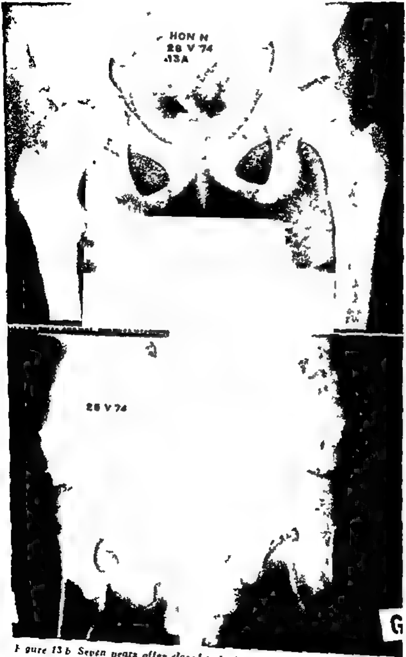



Figure 13 b Seven years after closed reduction and innominate osteotomy


*Figure 13 a Congenital dislocation of the left hip and subluxation of the right hip in girl aged 5 years 9 months*

and good results in 85 4 per cent of the cases There was only one poor result In the 17 hips in children between 4 and 8 years of age (Figures 13 and 14) 58 8 per cent had excellent and good results There was one poor result and one complete failure

The complications observed during the treatment of these 72 dislocations are as follows

One case of avascular necrosis in an 8-year-old girl with an untreated dislocation Open reduction was performed and the head was reduced forcefully without the required shaft shortening

Seven cases of redislocations, distributed as follows One case by muscle retraction, set back into place by an iterative open reduction, this was the patient with avascular necrosis One case by technical failure of the innominate osteotomy, the hip was set back into place by closed reduction and made stable by a repeated innominate osteotomy

Four cases were due to excessive anteversion after repeated closed reduction for three and open procedure for one, anteversion was corrected by derotation osteotomy, results were all good except for one case which progressively subluxed

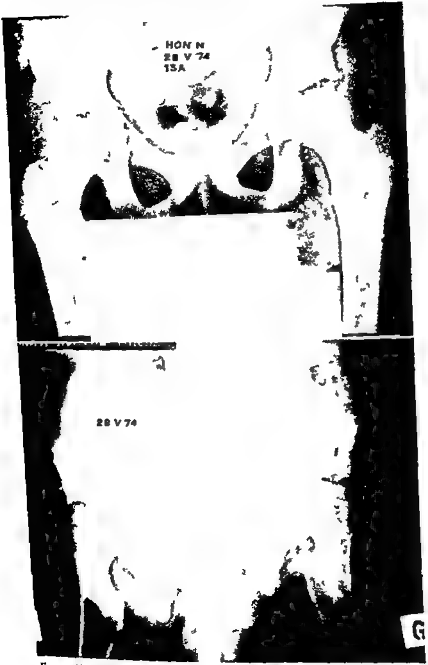
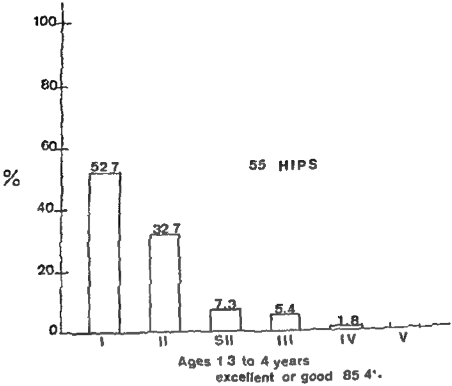
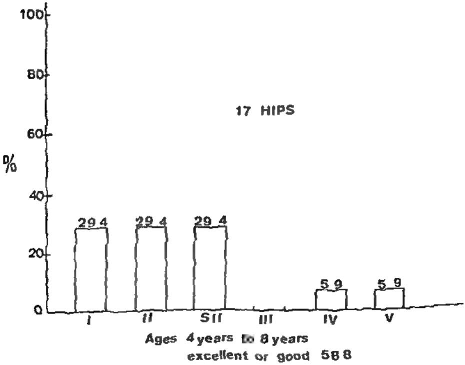



Figure 13 b Seven years after closed reduction and innominate osteotomy

*Table 2 Radiographic results of primary treatment for dislocation based on Severin classification*



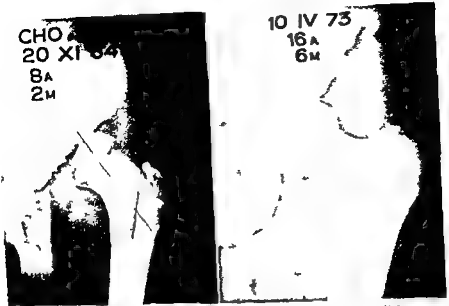



*Figure 11 Girl aged 8 years 2 months Congenital dislocation of the left hip open reduction after failure of closed reduction followed by innominate osteotomy 8 months later Normal CF angle at the end of growth (16½ years)*

One case of capsular laxity was a good result in the end after open reduction and capsulorrhaphy

Two cases of secondary displacement of the innominate osteotomy by insufficient fixation one case was reoperated with good result, the other was a poor anatomical result but the family refused iterative surgery owing to a good functional result

Four cases of skin perforation by the Kirschner wires

Seven cases of *transitory* stiffness after cast immobilization, four of which seem to have reasonable explanations two cases were open reductions and in the two others the wires had penetrated into the joint spaces The seven cases improved with unloading skin traction

In one case undisplaced supracondylar femoral fracture occurred during removal of the spica

## DYSPLASIAS AND SUBLUXATIONS

Treatment of congenital dysplasias and congenital subluxations is easier than in the case of dislocations since the prerequisite of reduction is already obtained In this case the head has not left its

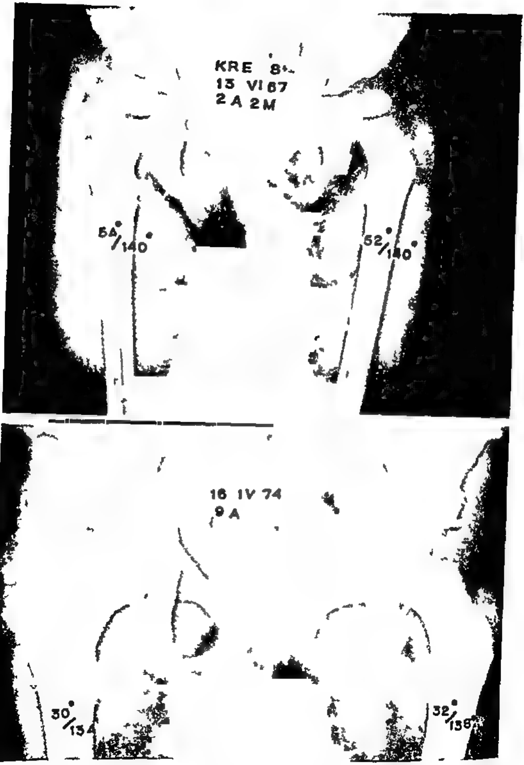


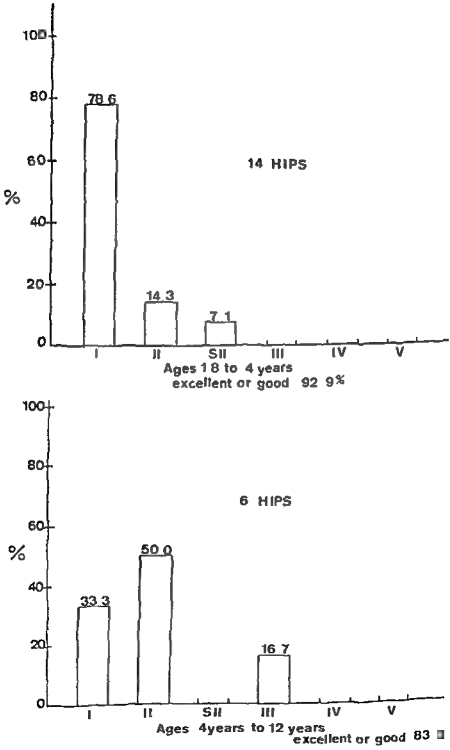

*Figure 15 Bilateral congenital subluxation in a girl aged 2 years 2 months Innominate osteotomy on both sides Result 7 years later (the anteversion of the femoral neck decreased)*

acetabulum and if concentricity is not *good enough*, it *remains* easy in most cases to replace the head in the bottom of the acetabulum since there is no interposition in a subluxation However, in older patients *good centering* of the head sometimes requires preparation by slow progressive skin traction It is used in all cases *associated* with a contralateral dislocation since both hips are then *subjected to traction* When the congruity is good, treatment of the dysplasia may then be undertaken It is logical nowadays to correct directly the maldirection of the acetabulum, since it is the most essential factor of the dysplasia Among pelvic *osteotomies* the best choice *appears to be Salter's in*nominate osteotomy As a matter of fact Salter's results (Salter & Dubos 1974) are so remarkable that it seems impossible to obtain better results with any other technique *100 per cent are good results before age 4* and 91 6 per cent after that age

We have *personally* used the same technique in 20 cases 8 cases of contralateral dysplasias or subluxations and 12 cases of isolated dysplasias or subluxations Six cases were considered to require combined derotation varisation osteotomy during the same procedure as the


*Figure 16 Untreated subluxation of the right hip in a girl of 12 years Result 2 years later after varisation derotation femoral osteotomy and innominate osteotomy*

*Table 3 Radiographic results of primary treatment for subluxation based on Severin classification*

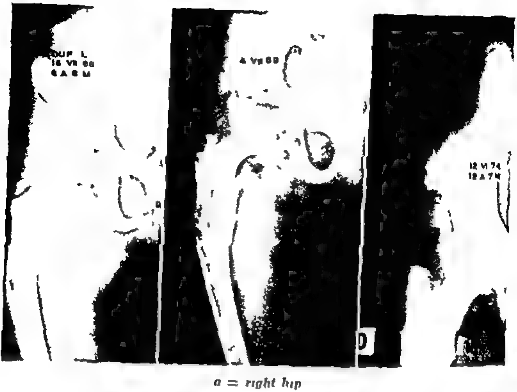


pelvic osteotomy In two cases femoral osteotomy was undertaken as a second stage procedure The minimum follow up period was 1½ years the maximum follow up was 9 years In nine patients the follow up lasted 5 years The graphs of our results are shown in Table 3 In patients under 4 years of age 92 9 per cent of our results were excellent or good One case was fair In patients more than 4 years old 83 3 per cent gave excellent or good results and one was considered a fair result After reviewing our cases we think that combined femoral osteotomy is not necessary in young children (Figure 15) As a matter of fact the percentage of excellent results is higher in the group which did not have femoral osteotomy We have noticed in several of these cases a spontaneous improvement of the femoral dysplasia particularly of the anteversion Consequently in the future we shall choose combined femoral and innominate osteotomy only in older children with severe subluxation (Figure 16)

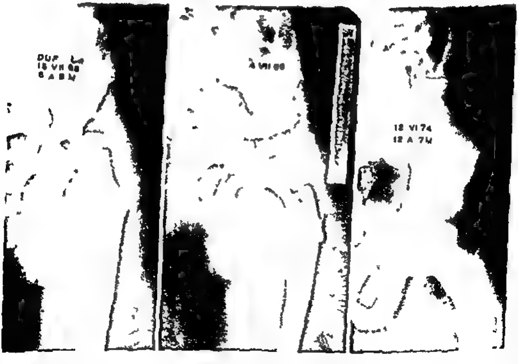
The complications in this group are as follows one moderate avascular necrosis in a 2½ year old boy who underwent a combined femoral and pelvic osteotomy This child had not had any traction prior to the operation As advised by Salter we should have tenotomized the adductor and the psoas in order to reduce the pressure on the femoral head One technical failure of innominate osteotomy reoperated at 3 weeks postoperatively in a 10½ year old girl One healing delay in an 8 year old girl Two cases of superficial sepsis

## RESIDUAL SUBLUXATIONS AND DISLOCATIONS AS SEQUELAE OF PREVIOUSLY TREATED MALFORMATIONS

Coxo-femoral dysplasias sometimes remain moderate but most often are important When encountered during growth after a previous treatment they raise difficult problems which up to now have been solved by femoral osteotomies which sometimes had to be repeated shelf operations and Colonna's arthroplasty Nowadays pelvic osteotomies allow a new approach and result in a progressive shift to new indications Two techniques have been specially developed Salter's osteotomy and Chiari's osteotomy From the mechanical viewpoint these two operations give an analogous result it improves the covering of the head and makes the hip stable However from the physiological viewpoint the result is quite different In the first case the head is covered by the cartilaginous portion of the acetabulum and the normal




*a = right hip*




*b — left hip*

*Figure 17 a b Bilateral residual subluxation in a girl age [illegible] years 8 months and results [illegible] years after combined varus femoral osteotomy and innominate osteotomy*

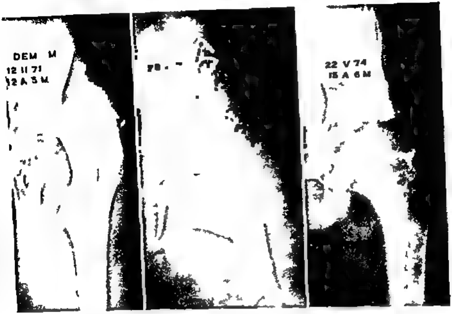



*Figure 18 Girl age 12 years 3 months Residual dislocation after open reduction of the left hip Open reduction by Klisic's technique and stabilization by innominate osteotomy in the same session Result 3 years later*

conditions of a joint are restored In the second case the head is covered by the bony slice of the proximal fragment and is separated from it only by capsular interposition These conditions actually create an arthroplasty This difference is significant indeed and as far as we are concerned it gives the preference to innominate osteotomy in children as long as their growth potential remains noticeable Nevertheless to be successful this operation has to comply with prerequisites which are not met in all cases It is first necessary for the head to be centered and reduced in the true acetabulum without this, innominate osteotomy should not be done X ray films prior to the operation are therefore necessary to determine whether simple innominate osteotomy or a combination of femoral and innominate osteotomy should be performed Our experience has shown that major coxo-femoral dysplasias were better treated by combined osteotomies (Figure 17) However varisation should not be overdone, since hypercorrection of the neck shaft angle might remain when growth is completed If the concentricity is not acceptable which happens particularly in fixed dislocations and subluxations one may still build up a new hip by combining open reduction and innominate osteotomy Open reduction

will be *performed through a Watson-Jones approach* with the required femoral shortening as described by Klisic. Innominate osteotomy will then be done through the usual approach, in the same operative stage whenever possible. Before starting such a difficult treatment a second requisite will be *to determine the possibility of achieving good joint* reconstruction. Our experience has made us aware that the potential of head remodelling remains for a long time. On the condition that a normal articulation relationship has been restored within the joint one may expect *good results up to 12 years of age* (Figure 18). The sometimes astonishing results obtained have made us completely abandon Colonna's arthroplasty. When the prerequisites are not all met, our indication is then a Chiari osteotomy. The author suggests this operation for children more than 4½–5 years old. We think that the growth potential remains so important at that age that an innominate osteotomy is the better choice if the concentricity of the reduction is good. We reserve the Chiari ostotomy for *fixed subluxations in older children at the end of growth*. It seems to be the best indication in such circumstances. However, our experience is not very extensive and we have not included in this work the only case that we treated in such a way.

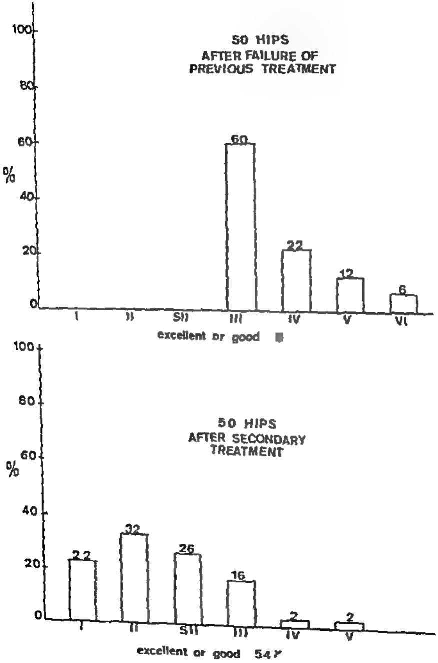
Table 4 gives the results of 50 residual subluxations or dislocations after previous treatment. Thirty-two cases were treated by simple innominate osteotomy, 13 cases by femoral + innominate osteotomy and 5 cases underwent open reduction prior to innominate osteotomy. When femoral osteotomy was performed, it was done at the same time as innominate osteotomy in all but three cases: twice it was done before, and once after. Femoral corrections were mainly varisations in 10 cases, derotation twice, and combined varisation-derotation once. Twenty-nine cases were followed-up for 5 years or more. The maximum follow-up was 10 years. The minimum follow-up was 1 year. The two graphs in *Table 4 show the state of those 50 hips prior* to and after treatment. Whatever the difficulties of the treatment, 54 per cent of the cases had excellent and good results.

The complications observed are as follows.

One case of avascular necrosis in a 15-year-old girl. After a 6 week period of progressive skin traction reaching 9 kg, the surgical phase required a 25° varisation femoral osteotomy + innominate osteotomy. The tilt of the distal fragment was difficult and we were wrong not to do the usual tenotomies prior to it.

One technical failure of the innominate osteotomy in the first case of the series in 1964.

*Table 4*


50 HIPS
AFTER FAILURE OF PREVIOUS TREATMENT
100
80
60
40
20
0
%
60
22
12
6
I
II
SII
III
IV
V
VI
excellent or good
100
80
60
40
20
0
%
50 HIPS
AFTER SECONDARY TREATMENT
22
32
26
16
2
2
I
II
SII
III
IV
V
excellent or good 54 %

Three insufficient fixations with post-operative displacement Two patients were reoperated upon early with a good result, the third case was done 2½ years later with a fair result.

One sepsis with joint involvement healed well without sequelae after prolonged antibiocytherapy.

Four superficial sepsis cases, among which two led to displacement at the osteotomy site after premature removal of the Kirschner wires

One case of transitory painful stiffness after plaster cast removal

## CONCLUSION

*Two factors have been* emphasized in this review: slow progressive traction with abduction and internal rotation, and innominate osteotomy. The first procedure prevents avascular necrosis, and the second one prevents residual coxo-femoral dysplasia These are two important notions which will allow us in the future to further improve our results in this field.


## SUMMARY

Two additional risks are involved in the treatment of congenital dislocation of the hip when diagnosis is made too late: avascular necrosis folowing the reduction, and residual coxo-femoral dysplasia Our study and the experience that we acquired within the past 10 years on 142 hips show the value of closed reduction by slow progressive traction with abduction and internal rotation, and the value of innominate osteotomy These are two strong points on which we can base our treatment in order to further improve the results of our efforts in this field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Acta orthop scand 46, 400–424, 1975

Minneapolis, Minnesota U S A

# SCOLIOSIS AND OTHER SPINAL DEFORMITIES

ROBERT B WINTER

## I RECENT SCIENTIFIC DEVELOPMENT

The past 20 years have brought about tremendous change in the field of scoliosis and related spine deformities There has been considerable improvement in surgical technique in terms of the quality of fusion and strength of the fusion mass We have seen the development of two major techniques of internal correction and fixation Harrington rods and Dwyer instruments We have seen the development of more powerful methods of external spine correction, including Cotrel traction, halo-femoral traction and halo-hoop techniques We have seen advancement of surgical technique into new and innovative attacks upon spine deformity, most particularly the development of anterior spine fusion as well as corrective osteotomy of the spine Finally, we have seen improvement of non-operative techniques with the introduction of new types of braces as well as refinement of traditional braces

This wealth of new techniques, materials, and methodologies has brought tremendous change and provided a quality of care previously thought impossible Previously hopeless problems have become possible, and previously difficult problems are now routine

The innovative surgical techniques of anterior surgery and wedge osteotomy, as well as the more powerful corrective forces involved in Harrington rods, halo hoops and halo-femoral traction, have brought about an *increase* of neurologic complications related to either direct spinal cord trauma or to ischaemia of the cord Thus, the advancements in techniques have not always been coupled with increased safety to the patient

## II IMPORTANT DATA

The most common cause of spine deformity, idiopathic scoliosis, remains as much an engima as it has previously been Although there

have been small inroads into the basic nature of this problem, the ultimate cause is still unknown

## A *School screening*

Probably the most significant new information regarding idiopathic scoliosis has come from those studies involving screening of large numbers of schoolchildren for spine deformity These screening procedures have been done in many different areas, including Johannesburg, South Africa, and California, Minnesota and Delaware, and have shown that idiopathic scoliosis is a far more common problem in most countries than was previously realized Earlier studies had indicated an incidence of 0 1 to 0 2 per cent based on the number of patients coming to physicians for treatment or for evaluation of mass X ray screenings for tuberculosis

Evaluation of large numbers of schoolchildren has revealed an incidence of scoliosis of up to 12 per cent when screening children aged 10 14 years Most of these patients have very small curvatures, i e in the range of 5–15 degrees (Cobb) At the younger age levels, that at ages 10 and 11, the condition is found almost equally in males and females As the children mature, the percentage of significant curvature rises most in the female Thus, the number of older children requiring treatment (having progressive curves or curves greater than 20 degrees) shows a predominant female incidence similar to that previously known (approximately 80 per cent female – 20 per cent male)

These findings indicate that perhaps the feminine dominance of the condition is not a genetic one i e, it is not a sex linked dominant factor, but rather the incidence is the same but the tendency towards progression may be governed by hormonal factors Thus investigations into growth and sex hormones have assumed a greater significance in the search for the cause of idiopathic scoliosis

The school screening studies in South Africa revealed a significant difference between Negroes and Caucasians the incidence in Negroes being approximately 2 per cent and that in the Caucasians approximately [illegible] per cent Both of these studies were conducted in the Johannesburg school system, so the quality of analysis appears to be the same in the two groups These results indicate a very definite ethnic relationship of this condition

The school screening program has not only given us intriguing

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The school screening program has not only given us intriguing

information regarding cause of idiopathic scoliosis, but has, from the point of view of practical application of treatment, given us the ability to control idiopathic scoliosis without surgery in the majority of patients

It has become increasingly evident that non-operative brace treatment, regardless of what type of brace is used, is effective only when curvatures can be detected early in the course of the curve before significant rigid structural deformity develops The only way to find children when they are in this early, treatable stage is by mass screening techniques

### B *Surgical treatment of idiopathic scoliosis*

The significant data that have evolved during the past 5 years concerning surgical treatment of idiopathic scoliosis are primarily related to the quality of the correction as well as the quality of the fusion mass created There is now a good guarantee of permanent stability of correction Operative techniques have gradually been improved to the point where the surgical treatment of idiopathic scoliosis in the adolescent should yield correction of between 50 and 60 per cent of the original curve, with an infection rate of 1 per cent or less, a pseudarthrosis rate of 2 per cent or less, and a minimum of other complications

This high degree of success has come from a combination of facet joint excision, replacement of the facet joint with autogenous iliac cancellous bone, thorough decortication of the entire fusion area, and addition of further autogenous iliac bone These results are being duplicated by many scoliosis surgeons throughout the world at this time The days of considering a 10 per cent pseudarthrosis rate as acceptable are past

### C *Early ambulation*

Reports from several centres now indicate that early ambulation following surgery can produce results equal to or better than those obtained by 3–6 months of bedrest Early ambulation has been possible by a combination of secure internal fixation with Harrington or Dwyer instruments followed by application of snug, well fitting, comfortable, total contact casts or expertly designed braces Statistical analysis of such treatment indicates an average loss of only 5 degrees from the time of surgery until 1 year later in adolescent idiopathic scoliosis

The arthrodesis appears to heal more strongly with vertical loading of the spine. Thus, the fusion appears to be stronger at the time of cast removal and there is less tendency for loss of correction following cast removal. Furthermore, there are tremendous psychologic benefits to the child in being able to leave the hospital, to return to regular school, and to participate in most activities with his or her peers.

D. *Dwyer instrumentation*

The Dwyer procedure has gained increasing acceptance during the past 5 years. It is still considered to be in an experimental phase with relatively few statistics available as to the results, but some facts are clear. It is a very powerful correcting device. It is most applicable to the thoracolumbar area, that is, between T 9 and L 4. The instruments themselves are sufficiently strong and durable to maintain correction, providing that firm external support is also used in the form of a cast or brace.

The *major* problems with the Dwyer procedure have been: a) the necessity for an anterior approach; b) the inability to fuse extensive areas of the spine, as *one* is limited by convenience to approximately six levels; c) the still somewhat awkward design of the instruments of insertion; d) inability to reach and anchor well in the sacrum. In most centres, the Dwyer procedure is used *predominantly* in neuromuscular problems, usually combined with a secondary posterior operation of greater length, and usually with Harrington instrumentation. The risk of paralysis due to interruption of the blood supply to the spinal cord was felt by *many* to be a strong contraindication to the Dwyer procedure. This has, however, not proved to be a significant factor to date.

I. *Anterior spinal surgery*

Anterior spinal surgery, initiated primarily for the treatment of tuberculosis of the spine, has come to play a significant role in the treatment of many other causes of kyphosis. Progressive or severe kyphosis is *seldom* permanently stabilized by posterior arthrodesis. From a biomechanical point of view, a posterior arthrodesis is under tension or distraction forces and does not knit solidly. However, an anterior arthrodesis is under compression forces and tends to knit strongly.

Therefore, for such conditions as neurofibromatosis kyphosis, ad

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The most significant role of the anterior approach besides that of anterior fusion has been anterior decompression of the spinal cord when the cause of the compression of the cord is anterior There are a multitude of reasons for anterior cord compression but statistically the most common are a) congenital kyphosis b) trauma c) neurofibromatosis kyphoscoliosis, d) postlaminectomy kyphosis e) the *kyphosis due to various types of osteochondrodystrophies* and f) tuberculosis The pioneering work of the tuberculosis physicians which achieved such excellent results in the decompression of the spinal cord has led to greater recognition of the role anterior cord decompression plays in other aetiologies The transthoracic route has been the most beneficial, since it is possible to perform an adequate anterior arthrodesis at the same time, thus stabilizing the kyphosis and preventing continued collapse The Capener costrotransversectomy approach does not provide adequate exposure for arthrodesis or abcess excision

## F *Brace treatment*

Statistical anlyses of the results of the Milwaukee brace and other braces in treatment of idiopathic scoliosis are now available Three independent review articles indicate that the Milwaukee brace is most effective in adolescent idiopathic scoliosis of between 20 and 40 degrees Between 40 and 50 degrees the results are only fair and above 50 degrees the results are poor Curvatures of 50 60 degrees in juveniles (ages 3 10) can well be treated by braces These are less frequent patients The average results from three different centres indicated approximately 20 per cent improvement of the curve at the conclusion of treatment Analysis by Dr Blount of patients who had been out of their braces several years has indicated that there is a tendency to lose a few degrees of correction particularly following *pregnancy* At the present time no statistical results are available on patients several years after the completion of brace treatment

Statistical analysis of end results of Milwaukee brace treatment for Scheuermann s disease are now available Excellent improvement was obtained in the brace and maintained after brace removal The final results indicated approximately 40 per cent correction of the kyphosis and also 40 per cent correction of the wedging of the apical vertebrae

## III TODAY'S LEVEL OF PERFORMANCE

### A Idiopathic scoliosis

The treatment of idiopathic scoliosis involves only three methods The first is controlled observation, the second is non operative treatment with a brace, and the third is surgical correction and fusion The physician treating the child has relatively few choices to make, but he may have difficulty deciding which is the best method

Careful observation without active treatment can be done for slight curves that is curves of 0 to 15 or 20 degrees As long as the child is growing periodic observation is necessary Upright X rays should be carefully measured to see if progression is or is not taking place If the curve is progressive, then brace treatment is indicated

The choice then lies between which type of brace is the most effective At the present time, the Milwaukee brace is the treatment of choice for thoracic curves Underarm level corrective braces appear to be quite satisfactory for flexible thoracolumbar and lumbar curves

A properly made Milwaukee brace has a well fitting pelvic girdle with elimination of lumbar lordosis in the taking of the model and in the manufacturing of the brace There are two posterior uprights and a single anterior upright with a metal neck ring containing two small occipital pads and a throat mold The old flat chin pad is no longer used due to the high incidence of resulting dental abnormalities The occipital pads must be situated *below* the occiput and there must be at least 1 0 cm between the throat mold and the tissues beneath the chin when the patient is standing in a neutral position and looking straight ahead

Various lateral holding pads are used depending upon the nature of the curve There are lumbar pads oval pads, L-shaped thoracic pads shoulder rings and trapezius pads The lumbar pad is used only for lumbar curves For thoracolumbar curves a lumbar pad plus an oval pad on the lower most ribs (both on the *same side*) is the preferable application For the usual thoracic curve the L-shaped thoracic pad is used plus an axillary sling on the opposite side to balance the neck in the centre of the brace The axillary sling is a balancing device, not a curve correction device The trapezius pad and shoulder ring are used for high thoracic or cervicothoracic curves

The Milwaukee brace is combined with an active exercise program which obtains a better correction of the curve due to active curve correcting exercises and maintains good spinal muscle tone so that

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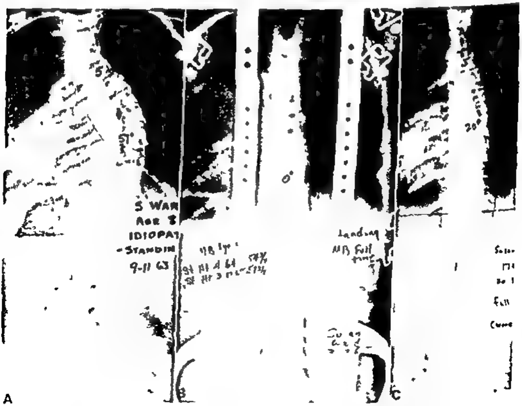


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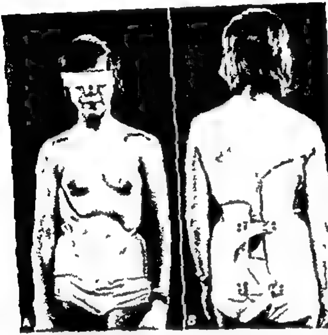


*Figure 3 A B Front and back views of a patient with a brace for a lumbar idiopathic scoliosis Her 25° left lumbar curve is reduced to 6° in this brace*

at the time of brace removal, good muscles are available to maintain the upright and corrected position

Exercises without brace treatment are of no value in the treatment of any kind of scoliosis They do not correct a curve and they delude the patient and physician into thinking that something positive is being done

For thoracolumbar and lumbar curves, the new underarm-level corrective braces appear to be *excellent* Newer designs are made of strong plastic materials and are psychologically very pleasing to the patients These are made with the patient in the corrected position and

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*Figure 1 A modern Milwaukee brace The pelvic girdle is made of a plastic (polypropylene)*

*Figure 2 A An 8-year-old girl with a 57° right thoracic idiopathic scoliosis B After 1 year of treatment in a Milwaukee brace the curve has been corrected to zero degrees C Age 17 years 5 months One year after complete brace removal The curve measures 20°*

must eliminate lumbar lordosis For this reason, they must be brought low in the region of the buttocks but cut high in the front to permit comfortable sitting The abdomen must be kept firmly supported to prevent lumbar lordosis, thus allowing the lateral component of the corrective force to be effective against the lumbar spine These braces are not effective for curves greater than 40 degrees

The experiences of the past 5 years would indicate that all types of braces are primarily devices to prevent curves from increasing rather than devices to correct an already significant curvature Therefore, to be effective, any type of brace must be applied when the curve is mild with the thought that it will keep the curve mild The physician who believes that he can correct a 60-degree curve with a brace is only deluding himself There may be some application for braces in the traatment of 60-degree curves in idiopathic, infantile and juvenile idiopathic curves- but certainly not for the treatment of adolescent idiopathic scoliosis

The main problem areas confronting the physician using brace treatment are the two borderline areas of the mild curve and the more major curve In the mild curve, the question arises, should the child be observed or braced? Curves of less than 20 degrees usually are not braced unless it is known that they are progressing For example, if a child is seen for the first time with an 18 degree curve and is 13 years of age, then treatment is usually postponed until a check up 3 months later can show whether progression has taken place If it is progressive then a brace will be applied

If, however, the patient has previously been seen with a 10 degree curve and on follow-up has progressed to 18 degrees, then brace treatment would be instituted without further delay

The reason for using 20° as the dividing line is that school screening examinations of large numbers of children have indicated a very large number of children with curves of under 20° that are non-progressive or even self-resolving Above 20°, however, the curves usually progress and do not resolve spontaneously

The other major area of difficult decision-making is that of the more significant curve and here it is a question of whether it requires a brace or surgery The past 5 years have brought the realization that braces cannot correct major structural curves Thus, the indications for the brace have narrowed and the indications for surgery have increased somewhat as compared to 5 or 10 years ago Curves up to 40 degrees can easily be braced and curves above 50 degrees should be

operated on (adolescent idiopathic scoliosis) and thus the area of difficult decision making is in the range of 40–50 degrees. Under these circumstances, the younger the child or the more structural the curve, the more likely it is that surgery is necessary. Thus, a 45 degree curve which corrects on supine side bending to 10 degrees and is associated with a 1.0 cm rib hump in a child prior to menarche would be a brace candidate, whereas a 45 degree curve in a 14-year old girl 1 year after the onset of menses with side bending to 30 degrees and a 3.0 cm rib hump would be a surgical candidate. Curves above 60 degrees in adolescents should be corrected and fused without question. With curves of this magnitude, the incidence of complications in adult life are so frequent as to justify treatment in the child. Curvatures above 60 degrees are now known to be progressive in adult life. Thoracic curves above 60 degrees tend to give respiratory complications. Lumbar curves are more controversial than thoracic curves, many physicians believe that lumbar curves do not cause problems later and therefore do not need surgical correction and fusion. Other surgeons, particularly those who see a large number of adult scoliotics, believe that lumbar curves produce a high incidence of arthritis and progression during adult life and therefore should be corrected and fused. The statistics needed to definitely answer these questions are not available at the present time.

Surgical treatment of idiopathic scoliosis has slowly evolved to a standardized procedure in the major centres throughout the world. At the present time, the most commonly used method is spinal fusion supplemented by Harrington instrumentation. The Harrington instruments have become standardized throughout the world and have, in essence, become the routine method of treatment for adolescent idiopathic scoliosis.

The operative procedure consists of a straight incision with careful subperiosteal dissection of the entire fusion area of the intended arthrodesis. With extremely careful subperiosteal dissection, blood loss can be maintained at a minimum level, a level which previously had not been thought possible. After careful exposure and removal of all soft tissues from the spine, from the tip of the transverse process to the tip of the opposite transverse process, the facet joints are then excised completely and all cartilaginous surfaces removed. The area of the excised joint is then filled with a bone graft of autogenous material, while others prefer to use plugs of autogenous iliac cancellous bone. The author much prefers the autogenous iliac bone plug in each and

every facet joint throughout the fusion area After these have been inserted, the entire fusion area is decorticated thoroughly down into the cancellous bone, again from tip of transverse process to tip of transverse process The Harrington instrument is then inserted placing the distraction rod along the concave side of the curve, the upper hook being inserted into the facet joint and the lower hook being inserted underneath the lamina of the end vertebra in the fusion area The Harrington contraction assembly is a more controversial part of the instrumentation Some physicians are routinely using it and others routinely not using it The Cotrel transverse osteotomy to correct the rib hump has been adopted by many surgeons and does give a more significant improvement in the rib hump than can be achieved by any other means

The use of an abundant autogenous iliac bone graft in each and every case has provided a fusion mass of consistently high quality The pseudarthrosis rate has steadily dropped thanks to competent surgeons and is now approximately 1 per cent in the major centres healing idiopathic scoliosis

After insertion of the Harrington rod and placement of the bone graft, the incision is then closed with a careful cosmetic suture of the skin using intra-cuticular wire or other suture material Heavy, tight sutures in the skin produce an ugly scar and thwart the cosmetic intentions of the surgery

Approximately 1 week after surgery, the patient is placed in a very snug type of cast that uses traction, derotation and lateral flexion forces at the time of cast application If the Harrington instruments have been properly applied, they will not be loosened by application of the cast A very snug form-fitting plaster provides total contact and permits early ambulation Ambulation is begun during the second week after surgery and the plaster is maintained for 6–9 months, depending on the age of the child, the quality of the fusion and the experience of the surgeon A cast time of less than 6 months is to be condemned, as bone simply does not mature in less time than that Large windows are placed anteriorly in the thorax to allow maximal inspiration and expiration This permits the ribs to continue moving and avoids a "frozen thorax" It also avoids pressure on the breasts and maintains a normal vital capacity

For the patient with adolescent idiopathic scoliosis, it is not necessary to apply a brace or other device once the cast is removed at the end of the healing period A solid fusion in an adolescent will

not regress unless there is a pseudarthrosis Pseudarthroses should be surgically repaired

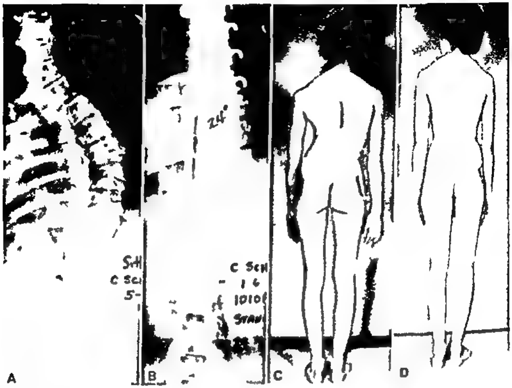
Juvenile idiopathic scoliosis, that is idiopathic scoliosis occurring between the ages of three and the onset of puberty, continues to be more rare than adolescent scoliosis, particularly in the United States The Milwaukee brace has proven to be extremely valuable in the treatment of these children by preventing rapid deterioration of the curve In some patients with idiopathic scoliosis the Milwaukee brace provides such superior correction that surgery is permanently avoided Other children do not benefit as well, in that the brace delays the need for surgery until the age of 10 12 but then, with the growth spurt, the curve begins to deteriorate and surgery cannot be delayed further Surgery should never be delayed until the end of growth and should always be done prior to this time

Infantile idiopathic scoliosis continues to remain an enigma The most beneficial recent development is the "rib vertebral angle difference" measurement of Mehta, who demonstrated that one can use this special measurement technique to predict whether the curve will be progressive or not A difference of more than 20 degrees in the relationship of the angle of the rib to the vertebral body when comparing the two sides is an indication of a progressive curve It is a measurement of the structural character of the curve Infantile idiopathic curves which are progressing or which have gone more than 30 degrees or have a rib vertebral angle difference of greater than 20 degrees, should be treated by brace, preferably the Milwaukee brace It is now possible to treat children as young as 8 months of age with a well fitting Milwaukee brace

B *Congenital spine deformities*

With the disappearance of poliomyelitis scoliosis from many parts of the world congenital spine deformities have assumed a more prominent place in scoliosis clinics With increasing surgical ability, it has been possible to do many more things for congenital spine deformity than has previously been thought possible

The fundamental treatment of congenital scoliosis still remains standard cast correction and posterior spine fusion at an early age before the curvature becomes severe In congenital scoliosis, the severe curvatures resist correction and, therefore, surgery must take place early Early fusion is not as harmful in congenital scoliosis as in

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other scolioses, since the fusion area can be relatively short and the anomalous area does not grow normally anyway, thus taking away the potentially negative growth effects of surgical arthrodesis

Sometimes a four or five level arthrodesis at the age of 4 or 5 years can solve a curve problem for life In such circumstances, it is the ideal thing to do, thus avoiding years and years of brace treatment or progressive curvature Brace treatment remains relatively poor for congenital scoliosis, being applicable only to those curves which are long and flexible Short, rigid curves should be fused promptly

Congenital kyphosis has been increasingly recognized as a very dangerous problem because of the high incidence of spinal cord involvement Statistics from several centres have indicated that the single most common cause of spinal cord compression due to spine deformity (excluding tuberculosis) is congenital kyphosis It may be either congenital kyphosis or congenital kyphoscoliosis

The essence of treatment of this dangerous problem is early recognition and early, prompt and abundant posterior fusion Once beyond 50 degrees of kyphosis, these deformities are very difficult to correct and to fuse by posterior arthrodesis alone Over 50 degrees and beyond age five, both anterior and posterior spine fusion are required

Anterior spine fusion has come to play a very important role in any neglected and difficult cases of congenital kyphosis It offers an opportunity not only to obtain a stable arthrodesis, but also to do anterior osteotomy and correct the spine deformity as well

When the patient with congenital kyphosis develops paraplegia, anterior transthoracic spinal cord decompression and anterior spine fusion plus posterior spine fusion is the procedure of choice Laminectomy must be avoided

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*Figure 4 A  L.S. A 11 year 10 month old girl with a 62° right thoracic idiopathic scoliosis This amount of curve requires surgery and cannot be treated by braces B  L.S. 29 months following surgery The curve has been permanently corrected to 21 Note the use of both distracting and contracting instruments C. The patient before surgery D The patient 1 year after surgery*

*Figure 5 A  S.G. A 14 year old girl with a 75° right thoracic idiopathic scoliosis B  S.G. A spine x ray taken the day of surgery showing correction to 20° utilizing a preoperative Risser cast and a single distraction rod C  S.G. 19 months after surgery Curve is solid at 20° Her postoperative cast was applied on the 6th postoperative day she was ambulated on the 7th postoperative day was discharged from the hospital on the 10th postoperative day and returned to school on the 16th postoperative day*

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Figure 7. A — F.M. A 3 month-old infant with a 32° congenital scoliosis due to an unsegmented bar. Note the single kidney, hydroureter and hydronephrosis. There is obstruction at the uretero-vesicle junction. She was seriously ill with a urinary tract infection at this time but was saved by ureteroplasty and antibiotic therapy. B — F.M. at age 2 years 5 months. Note the rapid increase in her scoliosis, now 6? . A posterior fusion was done elsewhere at age 3. C — F.M. Age 9 years. Curve measurement 5?°. The curve is extending both upward to T 1 and downward to L 3. D — F.M. Two years after anterior wedge osteotomy at T 8 and L 1 on the left, followed 2 weeks later by posterior wedge osteotomy and halo-turnbuckle cast correction. E — F.M. Front view at age 9 before surgery. F — F.M. Front view at age 11, 2 years after surgery.


*Figure 6 A D.W. A 15 year old male with congenital kyphosis back view (patient of Dr Moe's) B Lateral supine x ray kyphosis 125° C Lateral standing x ray 1 year after surgery (anterior release osteotomy rib grafting Harrington instrumentation and halo cast) D Posterior view 1 year later*

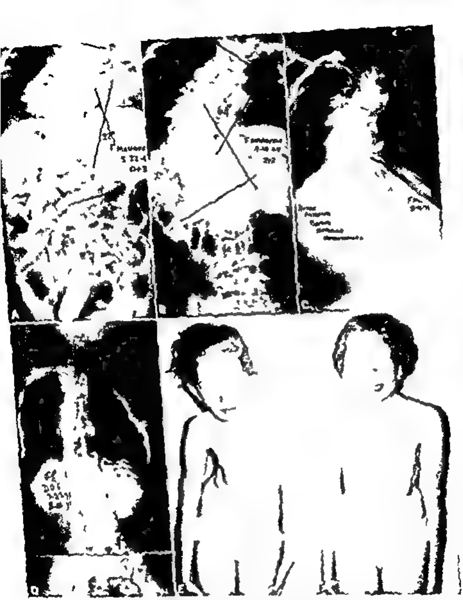

*Figure 7 A F.M. A 5 month old infant with a 32° congenital scoliosis due to an unsegmented bar. Note the single kidney, hydroureter and hydronephrosis. There is obstruction at the uretero vesicle junction. She was seriously ill with a urinary tract infection at this time but was saved by ureteroplasty and antibiotic therapy. B F.M. at age 2 years 2 months. Note the rapid increase in her scoliosis, now 64°. A posterior fusion was done elsewhere at age 3. C F.M. Age 9 years. Curve measurement. The curve is extending both upward to T1 and downward to L3. D F.M. Two years after anterior wedge osteotomy at T6 and L1 on the left, followed weeks later by posterior wedge osteotomy and halo turnbuckle cast correction. E F.M. Front view at age 9, before surgery. F F.M. Front view at age 11, 2 years after surgery.*

Osteotomy of the spine or hemivertebra excision has been performed increasingly often during the past 5 years Indications still remain difficult to define precisely As an absolute indication, wedge osteotomy is indicated in fixed deformities which are life-treatening if this procedure is not carried out It is not indicated purely as a cosmetic procedure It seems to be most helpful in those patients with lumbar hemivertebra which create a marked lateral translation of the thorax relative to the pelvis In these cases, the hemivertebra is usually in the L 5 area, below the conus, and therefore less dangerous to remove

Single-stage anterior-posterior hemivertebra excision has been performed but carries a very high risk as the incidence of paralysis has been three or four times higher than with two-stage removal Therefore, the two-stage excision technique as recommended by Leatherman is the procedure of choice if hemivertebra excision is deemed necessary The procedure consists of an anterior approach, either transthoracic if the hemivertebra is in the thoracic spine or retroperitoneal if it is in the lumbar spine, excision of the body portion of the hemivertebra and excision of the pedicle Nothing is done for 2 weeks, and then the midline posterior approach is made, excising the lamina, remainder of the pedicle and the transverse process The wedge is then closed, usually by a Harrington compression assembly, and a fusion of the appropriate length, depending on the nature of the curve, is performed Hemivertebra removal without fusion is not recommended It should be understood that this procedure does involve significant risk, as hemorrhage can be significant and there is always a risk of paralysis It should be performed only by individuals extremely competent in anterior spinal surgery

The Harrington instruments have been used for congenital scoliosis but appear to carry a significant risk of paralysis Analysis of paralytic complications from Harrington instrumentations shows that a very high percentage were patients with congenital scoliosis It appears that the spinal cord is often tethered either by diastematomyelia or other tethering structures and that the spinal cord does not have normal elasticity Thus, a relatively high percentage of patients having had Harrington instrumentation for congenital scoliosis have had varying degrees of paralysis Thus, Harrington instruments are not recommended as a method to obtain correction in patients with congenital scoliosis *Harrington instruments can be used, providing* correction is obtained by other methods, either cast or traction and the Harrington instrument is inserted only as a supporting structure without attempt to gain further correction

C *Paralytic scoliosis*

Although there has been a continued decline in the incidence of poliomyelitis, there continues to be a significant number of poliomyelitis patients in the world, and there continues to be a significant number of other types of neurologic disorders producing scoliosis The major improvements have concerned treating patients previously thought untreatable because of respiratory insufficiency This has been done through the use of positive respiratory support mechanisms This requires a very sophisticated medical technology and the assistance of people knowledgeable in respiratory management, particularly positive pressure and respirator care

The methods of correction have also improved and the use of halo hoop and halo-femoral traction has given remarkably greater corrections for severe scoliosis than previously thought possible Cast correction in paralytic patients is of very limited usefulness because these patients cannot tolerate corrective casts

Patients with significant lumbar curves (over 60 degrees) are quite often benefited by a combined anterior and posterior approach using halo-femoral traction to obtain the maximum correction, followed by Dwyer instrumentation anteriorly of the T 10 or 11 to L 4 area, followed 2 weeks later by posterior fusion with or without Harrington instrumentation This has provided magnitudes of correction previously thought impossible and a very secure internal fixation The interbody arthrodesis accomplished by the Dwyer reduces significantly the pseudarthrosis problem but the need for posterior fusion in addition to the Dwyer cannot be urged strongly enough It is very tempting to feel that the Dwyer procedure anteriorly is sufficient by itself for these paralytic curves, but it is not · Posterior fusion must also be accomplished and is the easiest way to obtain lumbosacral fusion

Previously, patients with paralytic curves fused to the sacrum were kept in bed for at least 6 months and in plaster for up to 12 months With these new management techniques it has been possible to return a patient to an upright ambulatory position in a well *fitting cast or* molded plastic brace 2 weeks after the second operation This cast or brace incorporates only the pelvis and does not immobilize either hip joint

This program does not totally eliminate the possibility of pseud arthrosis, but pseudarthrosis has been no more frequent under this programme than it has previously been with a cast down the legs and

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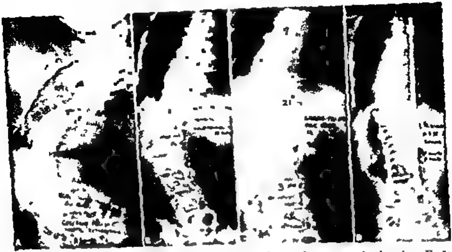

*Figure 8 A A 13-year old boy with a 100° scoliosis due to cerebral palsy B In halo femoral traction correction to 49° C Day of Dwyer instrumentation and anterior fusion T11 L4 D One year after posterior fusion T4 to sacrum with Harrington instrumentation from T4 to L3 (should have gone to S1) Curve 18°*

E *Adult scoliosis*

One of the most interesting developments in the past 5 years has been in the treatment of the adult scoliotic As various centres have become increasingly proficient in the treatment of scoliosis, large numbers of adults have come to these centres with problems related to curvature of the spine The most frequent complaint appears to be pain and this is most prominent in lumbar curves Patients with thoracic scoliosis are being seen because of progression of their curve during adult life

Previous statements indicating that scoliosis does not progress in the adult have proven to be wrong, and various reports have indicated a definite tendency for progression in the adult, particularly if their curves are greater than 50 degrees at the end of growth

Thus, an increasing number of adults are being treated for loss of lung capacity in thoracic curves or progressive [illegible]

[illegible]

[illegible] such as wound infection, pulmonary embolism, urinary tract infection and pseudarthrosis have been significantly higher in almost every series reported

Nevertheless, the improved technologies, especially Harrington in-

with prolonged bedrest The upright position seems to stimulate better fusion mass and can result in a reduced cast time by stimulating vertical trabecular formation The halo-hoop has often been recommended for paralytic curves, but it carries with it a significant problem of making it very difficult to fuse the lumbosacral area when the device is in place It is recommended that the correction be obtained by halo femoral traction if strong traction techniques are necessary and if ambulatory care in the halo-hoop is desired, the pelvic halo should be applied approximately 3 weeks *after* the arthrodesis Because of this problem, the halo hoop is most applicable to those types of problems where arthrodesis to the sacrum is *not* necessary

Braces have continued to be useful in paralytic curves providing the curve is small and flexible Orthotic treatment of paralytic scoliosis is not recommended for curves above 50 degrees, rigid curves or patients over 12 years of age Arthrodesis is usually preferable in such cases Brace treatment seldom provides permanent correction of the curve, but it is quite useful for delaying surgery until the optimal age The Milwaukee brace is most effective for thoracic curves and the molded plastic brace seems to be the most effective for lumbar curves

D *Neurofibromatosis*

Neurofibromatosis continues to remain a very troublesome cause of spinal deformity The incidence of pseudarthrosis remains high and the incidence of paraplegia is second only to congenital kyphosis (tuberculosis excluded) Paralysis is most likely to occur in those cases which have a kyphotic component in addition to the scoliosis The Milwaukee brace or other braces do not appear appropriate since statistical analysis of brace treated patients has shown them to be not effective in controlling the curve The procedure of choice remains arthrodesis There is a more than usual pseudarthrosis rate, and for most patients it is recommended that the fusion mass be explored 6 months after surgery and additional autogenous bone added regardless of how good the fusion appears to be at the time of the exploration A period of 1 year in a cast followed by Milwaukee brace or other brace treatment is recommended until the end of growth Patients with neurofibromatosis appear to easily tolerate correction with halo-femoral traction, Cotrel traction or halo hoop traction Harrington instrumentation in addition to the above fusion technique is a good method for neurofibromatosis curves provided the serious curves have previously been corrected by traction techniques

*Figure 8 A A 13 year old boy with a 100° scoliosis due to cerebral palsy B In halo-femoral traction correction to 42° C Day of Dwyer instrumentation and anterior fusion T11 L4 D One year after posterior fusion T4 to sacrum with Harrington instrumentation from T4 to L5 (should have gone to S1) Curve 18°*

E. *Adult scoliosis*

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Previous statements indicating that scoliosis does not progress in the adult have proven to be wrong, and various reports have indicated a definite tendency for progression in the adult, particularly if their curves are greater than 50 degrees at the end of growth

Thus, an increasing number of adults are being treated for loss of lung capacity in thoracic curves or progressive pain problems in lumbar curves Adults can be treated and a solid fusion obtained, but it is not as easy as in children or adolescents The complication rate is higher and such problems as wound infection, pulmonary embolism, urinary tract infection and pseudarthrosis have been significantly higher in almost every series reported

Nevertheless, the improved technologies, especially Harrington in-

strumentation and Dwyer instrumentation, have allowed adults to have surgery previously thought impossible Adults require ambulation following surgery as they do not tolerate bedrest well, either physically or psychologically Unfortunately, they *require a longer period of* immobilization to obtain a solid fusion and are less able to tolerate the external mobilization Therefore, it is important that they understand very carefully the length of time involved in treatment program

## F *Scheuermann's disease*

One of the most ignored of orthopaedic problems has been Scheuermann's disease In the past 2 years, significant series have been reported in terms of both surgical as well as brace treatment It seems apparent that not all patients with Scheuermann's disease can be ignored, as many both need and will benefit from treatment The best methods of treatment are plaster cast immobilization and Milwaukee brace treatment, both require correction of the curve and maintenance of the curve in the corrected position for a minimum of 1 year By this time, many of the patients with Scheuermann's disease will have healed spontaneously, and can be removed gradually from support without regaining their deformity Attempts to treat Scheuermann's disease by exercise alone or by underarm-level braces have universally failed

Surgical treatment of Scheuermann's disease has been attempted, but posterior fusion alone for the individual who has completed growth and has painful Scheuermann's disease has not been successful The posterior fusion mass is under distraction and usually most of the correction obtained at the time of surgery is lost Therefore, most centres treating these types of problems have concluded that both anterior and posterior arthrodeses are necessary if Scheuermann's disease is to be operated upon Surgery is rarely necessary for children with Scheuermann's disease since adequate brace or cast treatment will usually solve the problem in the growing child Surgery is recommended for the individual who has completed growth and has a significant amount of pain in the curve area

## G *Tuberculosis of the spine*

Tuberculosis of the spine continues to be a major health problem in many of the less developed areas of the world Even in highly civilized countries, an occasional case of tuberculosis of the spine is still found

and the lack of familiarity with its management can create problems

Very considerable progress has been made in the past 10 years in treating this ancient and difficult problem. Controlled studies in many areas have indicated that ambulatory treatment with drugs is successful in many cases, but 15–20 per cent of patients still have unresolved lesions or progressing deformities. When surgical facilities are available it appears most reasonable to excise the lesion, graft bone and immobilize. This, of course, requires an anterior approach to the lesion by the transthoracic route. The costotransversectomy approach provides the opportunity to drain an abscess but does not allow adequately excising a lesion or adequately bone grafting the spine.

For patients with paraparesis or paraplegia secondary to tuberculosis of the spine, the procedure of choice is the institution of drugs, stabilization of the patient's general condition, anterior transthoracic excision of the abscess with decompression of the spinal cord, plus anterior spinal fusion. This should be followed by posterior spinal fusion and adequate immobilization in a cast, usually a halo cast for thoracic spine, and a Risser cast for lumbar spine. Drug treatment alone is not recommended.

Drug treatment alone is indicated for early and mild lesions without significant collapse of vertebral bodies. If there is destruction of one or more vertebral bodies, then surgical excision in addition to drugs appears to be necessary. Thus, it is not a matter of surgery versus non-surgery, but selected patients should have only drugs and others should have both surgery and drugs.

Severe fixed kyphotic deformities have been most successfully treated in Hong Kong by anterior osteotomy of the spine, and correction in halo-hoop traction, posterior closing wedge osteotomy and fusion, and then anterior fusion. This is a long and extensive series of operations, but truly astounding results have been obtained in patients previously considered hopeless. Hopefully, the need for this extensive surgery will be eliminated by a more aggressive treatment of tuberculosis in its early stages.

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# ANKLE LESIONS

CARL-AXEL CEDELL

Few problems in traumatology have received such great attention and elicited such diverging opinions as the treatment of ligament injuries and fractures of the ankle Consequently the literature on ankle injuries is very comprehensive Lauge Hansen (1942) classified the evolution in ankle traumatology into three historical periods viz the clinical period the experimental period and the radiographic period Weber (1966) completed the list by adding two more periods, the genetical conservative period and the operative period In the early literature, French surgeons took a very prominent scientific position, while in modern times Scandinavian surgeons have been foremost in contributing to our present knowledge of the aetiology, diagnosis and treatment of ankle injuries

Ankle injuries are indeed very common Statistically, ankle sprain is the most frequent diagnosis in casualty departments of clinics of orthopaedic surgery This means that ankle injuries constitute a quantitative therapeutic problem that must be solved in the best way considering the available economic and medical resources however, the demand for high quality in the treatment must not be omitted

## *Anatomy*

The ankle is a rather complex *hinge joint* normally allowing only dorsal extension and plantar *flexion* It is however, greatly influenced by the subtalar joints where supination and *pronation* of the foot take place The ligamentous union between the distal fibula and the tibia is not quite *rigid* thus allowing small passive physiological movements viz some millimetres of lateral and proximal displacement and a slight outward rotation of the lateral malleolus These displacements appear when the talus takes up a position of dorsal extension in the ankle mortise because the trochlea tali is wider anteriorly than posteriorly

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*Key words* deformities spinal Dwyer instrumentation Milwaukee brace

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*Figure 1 Anterior drawer test The lower leg is pushed dorsally in relation to the fixed foot*

*Table 1 Distribution of ligament ruptures according to Broström*

| | % |
|---|---|
| Anterior talofibular ligament | 66.5 |
| Anterior talofibular + calcaneofibular ligament | 20.0 |
| Anterior tibiofibular ligament | 10.0 |
| Deltoid ligament | 2.5 |
| Anterior tibiofibular + deltoid ligament | 1.0 |
| *Total* | 100.0 |

known a fresh rupture of the anterior talofibular ligament is characterized by a haematoma corresponding to the talofibular joint The direct pain referable to the ligament is important However the indirect pain produced by the surgeon s gently forcing the foot in supination and inward rotation is far more important Even if the clinical examination suggests an injury to the anterior talofibular ligament it is often difficult to estimate the extent of the injury i e if the ligament

Lateral injuries are much more frequent than medial ones because of different strengths of the malleoli and the ligaments and because of the specific construction of the three subtalar joints. While the slender lateral malleolus is movable, the medial malleolus is a strong process of the tibia. The rather tiny lateral ligaments are clearly inferior to the solid deltoid ligament. The oblique axis of the subtalar joints favours movements in the direction of supination, and the supination capacity per se is also greater than the pronation capacity.

## *Ligament injuries*

Today we know that the anterior talofibular ligament is the most important stabilizing ligament of the ankle. This knowledge is based on experimental examinations performed by Dehne (1934), Pennal (1943) and Anderson et al. (1952). By sectioning the anterior talofibular ligament and the lateral portion of the joint capsule, they were able to prove that the foot could be displaced in a dorsoventral direction, thus producing a ventral subluxation of the talus. Andersen et al. also found that increased plantar flexion of the foot was accompanied by increased dorsoventral instability in the ankle. When the plantar flexion amounted to 20° they could displace the talus and the foot 7 to 8 mm ventrally. If the plantar flexion was increased to 35° they could, in addition to the displacement mentioned, also show the possibility for the talus to rotate in a medial direction. Staples (1965) and Coutts & Woodward (1965) have accounted for the clinical application of these observations and have shown that a rupture of the anterior talofibular ligament gives rise to a posteroanterior instability which can be roentgenologically registered. According to Broström (1966) the anterior talofibular ligament is damaged in nearly 90 % of all purely ligamentous injuries of the ankle (Table 1). As the anterior talofibular ligament is the most important stabilizing ligament, it is of course necessary that adequate diagnostic and therapeutic methods are available in order to prevent the occurrence of poor ligament healing and resulting instability. Chronic lateral instability most often means substantial symptoms of insufficiency and in the course of time the development of arthrosis deformans as well.

As to the diagnosis of ligament injuries of the ankle, there are both clinical and roentgenological methods. The *clinical* examination is very important. Unfortunately, its value is often underestimated, especially by the less experienced surgeon, who mostly relies on X-ray. As is well

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| Total | 100.0 |

known, a fresh rupture of the anterior talofibular ligament is characterized by a haematoma corresponding to the talofibular joint. The direct pain referable to the ligament is important. However, the indirect pain produced by the surgeon's gently forcing the foot in supination and inward rotation is far more important. Even if the clinical examination suggests an injury to the anterior talofibular ligament, it is often difficult to estimate the extent of the injury, i e if the ligament

rupture is partial or total, if only the joint capsule itself is damaged or if the injury is *restricted* to the soft tissue covering the ligament Then stability tests, especially the anterior drawer test, are very useful When the foot of the relaxed and above all surprised patient is pushed forward in relation to the lower leg, if the rupture of the ligament is total, one can register a marked pain reaction and very often also a ventral displacement of the foot (Figure 1) Sometimes the test can produce a clear crepitation when the foot is pushed forward Using this stability test, Lindstrand (1974) could diagnose total ligament ruptures quite accurately In a material of 100 patients clinically suspected of having a total rupture of the anterior talofibular ligament, he reduced the number of likely ruptures to 85 by using the anterior drawer test All injured ankles were operated on, and the ligament was found to be totally ruptured in 81 patients, i e the anterior drawer test gave a false positive result in four patients Those 19 patients who did not have a total rupture of the anterior talofibular ligament had instead a soft tissue lesion with bleeding (14 patients), a dorsal bone fragment avulsed from the talus (3 patients) or a rupture of the anterior tibiofibular ligament (2 patients) Thus, strangely enough, none of the 100 *patients had a partial rupture of the anterior talofibular* ligament, which obviously is a very rare type of injury Many surgeons prefer the patient to be somewhat anaesthetized when performing the anterior drawer test, for example by peroneal nerve block (Ruth 1961) or spinal anaesthesia (Broström 1966) Even local anaesthesia is often sufficient to make the examination painless

*Roentgenologically* the fresh total rupture of the anterior talofibular ligament can be diagnosed in different ways Plain radiography can reveal an incongruity in the joint between the talus and the fibula *(Cedell 1967) when the joint is examined at about a 20° inward rotation* of the leg (Figure 2) False negative examinations are registered in patients with pain and muscle spasm Sometimes plain radiography can also reveal the occurrence of small bone fragments avulsed from the lateral malleolus or very seldom from the collum tali

Stress radiography is more reliable than plain radiography With a total rupture of the anterior talofibular ligament, stress inversion radiography can register a talar tilt in a varus direction of up to 6–7° (Anderson et al 1952) The method is most appropriate for the diagnosis of combined ruptures of the anterior talofibular ligament and the calcaneofibular ligament Its clinical value is disputed, however, and strongly negative opinions about it have been expressed by Rubin

igure 2 *Rupture of the anterior talo ibular ligament with incongruity in he talofibular joint*

& Witten (1960) Stress inversion radiography has more and more frequently been replaced by the anterior drawer test, which is considered much more reliable (Castaing & Delplace 1972) and which does not require the surgeon s presence in the roentgen room The size of the ventral displacement of the talus is proportional to the extent of the injury, and the method can be used even on unanaesthetized patients if they are allowed to relax properly (Figure 3) As a rule both of the patient s ankles should be examined to discover a congenital hyper mobile ankle

Arthrography is stated to be a reliable method of proving a rupture of the anterior talofibular ligament Methods and roentgenological observations have been described by a number of authors, e g Wolff (1940), Hansson (1941), Palmer (1941), Hendelberg (1943), Berridge & Bonnin (1944), Percy et al (1969) and Fussel & Godley (1973) Bro strom et al (1965) have published a fairly comprehensive material of ruptures of the anterior talofibular ligament but consider the method to be reliable only within the first week after the injury In fact, arthrography has never been very popular as a routine method for diagnosing ankle injuries

rupture is partial or total, if only the joint capsule itself is damaged or if the injury is restricted to the soft tissue covering the ligament. Then stability tests, especially the anterior drawer test, are very useful. When the foot of the relaxed and above all surprised patient is pushed forward in relation to the lower leg, if the rupture of the ligament is total, one can register a marked pain reaction and very often also a ventral displacement of the foot (Figure 1). Sometimes the test can produce a clear crepitation when the foot is pushed forward. Using this stability test, Lindstrand (1974) could diagnose total ligament ruptures quite accurately. In a material of 100 patients clinically suspected of having a total rupture of the anterior talofibular ligament, he reduced the number of likely ruptures to 85 by using the anterior drawer test. All injured ankles were operated on, and the ligament was found to be totally ruptured in 81 patients, i.e. the anterior drawer test gave a false positive result in four patients. Those 19 patients who did not have a total rupture of the anterior talofibular ligament had instead a soft tissue lesion with bleeding (14 patients), a dorsal bone fragment avulsed from the talus (3 patients) or a rupture of the anterior tibiofibular ligament (2 patients). Thus, strangely enough, none of the 100 patients had a partial rupture of the anterior talofibular ligament, which obviously is a very rare type of injury. Many surgeons prefer the patient to be somewhat anaesthetized when performing the anterior drawer test, for example by peroneal nerve block (Ruth 1961) or spinal anaesthesia (Broström 1966). Even local anaesthesia is often sufficient to make the examination painless.

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two groups Because eighty per cent of the patients were cured by simple bandaging and had the shortest sick leave, too, and symptoms of instability can be managed by operation Broström recommended treatment with elastic bandage Objections can, of course, be made to his conclusions, e g why were his patients treated in plaster for only 3 weeks when the healing time for a ligament rupture by experience is at least 6 weeks? Many orthopaedic surgeons certainly hesitate to practice a method that gives 20 % remaining instability, especially as it is impossible to guarantee the patient total freedom from ankle trouble by a reinforcing operation

Immobilization in plaster, i e walking plaster for 6–8 weeks, is widely accepted and is considered to give good results (Hughes 1942, Pennal 1943, Leonard 1949, Cave 1958, Caro et al 1964, Russe 1967, Staples 1972)

Operative treatment entailing suture of the ligament is recommended by many surgeons as it appears to reliably prevent disability by producing a stable ankle (Bonnin 1950, Anderson & Lecocq 1954, Dziob 1956 McLaughlin 1959, Quigley 1959, Ruth 1961, Makhani 1962, Coutts & Woodward 1965, Niethard 1974, Reichen & Marti 1974) Everyone who has employed this treatment has seen convincing evidence of its efficacy Even if surgery probably is superior to other methods of treatment it should perhaps not be recommended generally Regarding the high frequency of total rupture of the anterior talofibular ligament, to always operate might mean that the operative resources of many hospitals would hardly be sufficient for other and more needed surgery Many reasons speak in favour of plaster treatment being used as a routine method and that the surgeon should carefully select those patients that should be operated on Probably only younger people should be treated by operation Two groups of patients should be selected 1, patients with fresh avulsion fragments belonging to the fibula or the talus and 2, patients who even before the actual injury have had symptoms of ankle instability (preferably old rounded bone fragments in the roentgenogram) In addition, one can of course consider operating if the patient is an active sportsman or his profession demands an absolutely stable ankle The recommendation to operate on injuries combined with avulsion fragments is based on the experience that these injuries often heal poorly, the ligament heals by fibrous union and with elongation resulting in repeated relapses of pain and swelling due to instability

Unfortunately some patients with a "healed" rupture of the anterior

*Figure 3 Anterior drawer sign registered by X ray*

Summing up, total rupture of the anterior talofibular ligament can be diagnosed with confidence when the anterior drawer test has been employed both clinically and roentgenologically

What, then, is the best way to *treat* the total rupture of the anterior talofibular ligament? Here opinions diverge strongly and the methods of treatment range from elastic bandaging to operation Freeman (1965) reported a surprisingly bad experience with ligament suture combined with plaster immobilization and suggested that mobilization might be the treatment of choice for most, perhaps all, ruptures of the lateral ligament of the ankle Brostrom (1966) was of the same opinion and thought that the injury should be treated by elastic strapping and early mobilization, which is, in fact, the treatment he recommends for all types of ankle ligament injuries His conclusion is based on three groups of about 90 patients each, where the treatment was respectively elastic bandage, walking-plaster for 3 weeks and operation in combination with plaster for 3 weeks At the follow-up examination the best results were found in the surgical group, where only 3 % of the patients had a remaining instability, against 20 % in each of the other

*Figure 4 Avulsion fragment belonging to the anterior tibiofibular ligament*

foot The ligament rupture can be roentgenologically diagnosed in those cases where there is an avulsion fragment from the tip of the medial malleolus or from the talus (Cedell 1974) and in those cases where the talus, owing to the ligamentous insufficiency, has been displaced in valgus position A fresh rupture of the deltoid ligament can also be established by stress radiography and arthrography Patients with avulsion fragments should be treated surgically, but as isolated ruptures of the deltoid ligament on the whole are so very rare it is probably a good policy to operate on them all

### *Malleolar fractures*

There is no sharp demarcation between ligament injuries and fractures of the ankle, as both lesions most often occur in combination In fact, isolated ligament ruptures constitute so called stage I injuries within the different typal lesions that characterize the ankle A ligament rupture is also called a fracture when the size of an attached avulsion fragment is large enough In more than 90 % of all malleolar fractures there is a total rupture of one or several syndesmosis ligaments The anterior tibiofibular ligament, for instance, is ruptured in about

talofibular ligament have residual symptoms of lateral pain and swelling in spite of full stability The reason for this phenomenon is not always quite obvious Sometimes there is a localized synovitis or a painful scar in the ligament Some patients have a functional instability because their fibular muscles are weak and perhaps even a proprioceptive deficit affecting the muscles of the ankle region (Freeman et al 1965) Sometimes there are also patients who, in spite of having an unstable ankle, are totally symptom-free, which fact indeed does not facilitate the surgeon's choice of the most appropriate method of treatment

*Chronic instability* of the lateral ligaments of the ankle, i e especially the anterior talofibular ligament, can be diagnosed much more easily and with the same methods as the fresh ligament injury Even here the anterior drawer test plays an important rôle both clinically and roentgenologically. The displacement of the talus is often very obvious and is accompanied by a marked pulling-in of the soft tissue in front of the lateral malleolus The treatment is operative Good results of treatment with Watson-Jones' operation or modifications thereof have been reported by Clayton et al (1951), Kelly & Jones (1951), Evans (1957), McLaughlin (1959), Stonham (1960) and Castaing et al (1967) Brostrom (1966) considers that the anterior talofibular ligament often can be dissected free and resutured even years after the original injury

*Isolated rupture of the anterior tibiofibular ligament* is a rare injury The reason for this is unknown but may be that the ligament is very strong and that a trauma severe enough to rupture it will also usually fracture the distal part of the fibula Clinically the injury is characterized by a direct and indirect pain localized in the anterior tibiofibular syndesmosis The indirect pain is produced when the surgeon outwardly rotates or even dorsally extends the foot while the lower leg is stabilized The injury cannot be diagnosed in the roentgenogram unless there is an avulsion fragment belonging to the anterior tubercle of the tibia (projection of 55° outward rotation of the leg Figure 4) The ligament rupture can be diagnosed by arthrography, too Treatment in plaster is sufficient for the healing of the ligament Patients with avulsion fragments should be operated on to avoid the risk of defective healing and residual symptoms localized in the anterior tibiofibular syndesmosis

Isolated rupture of the *deltoid ligament* is a very rare injury Clinically, pain and instability can be produced by forced pronation of the

*Figure 5 Pronation outward rotation injury of the right ankle (to the left) with a total rupture of the deltoid ligament and all the tibio fibular syndesmosis ligaments The distance between the arrows, la ligne claire (Chapat) is larger in the right ankle*

have been expressed by Lewis & Graham (1940), Bergstrand (1944) and Palmer (1941, 1944) Sneppen (1972), on the other hand, considers malleolar pseudarthrosis to be insignificant in the development of arthrosis deformans

As to the methods and means of achieving good joint reconstruction, the opinions of different authors are widely divergent Many surgeons consistently employ conservative treatment involving reduction and fixation in plaster and resort to operation only in those cases in which conservative treatment, in spite of repeated attempts, does not result in acceptable fracture position (Kristensen 1949, 1956, Bonnin 1950, 1965, Portis & Mendelsohn 1953, Fackert 1954, Watson Jones 1955, L Bohler 1957, Jergesen 1959, Kleiger 1961, Bedogni & Bergami 1962, Frankel et al 1963) Some surgeons believe that some injuries should be primarily operated on, such as displaced large posterior tibial fragments, displaced medial malleolar fragments and ruptures of the deltoid ligament, but in other cases they recommend conservative treatment (Müller 1945, McLaughlin & Ryder 1949, Cox & Laxson 1952, Trojan 1964, Buck Gramcko 1955, Dziob 1956, Braunstein & Wade 1959) Yet, other surgeons consistently employ operative treatment for every injury, reconstructing all or almost all of the injury components because, in their opinion, conservative treatment does not allow satis-

95 % of all supination-outward rotation injuries (Cedell 1967) and in all pronation and pronation outward rotation injuries except stage I

The *classification of the malleolar fractures* is very important and indeed constitutes a safe basis for the surgeon when he is treating the individual patient *In order to obtain good results of treatment* and above all not to miss important components of injury, every surgeon must be thoroughly familiar with the anatomy of the ankle and with the different stages of ankle injuries Today we employ the 'genetic classification of Lauge Hansen (1942), which is based on pathogenesis or the classification of Danis-Weber (1966), which is based on the position of the fibular fracture in relation to the distal tibiofibular syndesmosis

The *clinical* examination of a malleolar fracture is very important and should embrace the whole joint and also the whole fibula because a fracture sometimes can be situated as far up as the knee joint Stability tests are used only for the diagnosis of a rupture of the deltoid ligament, called by Staples (1960) "the invisible injury" The *roentgenological* examination should be performed in well defined and hence reproducible projections (Bolin 1961) Both ankles should be examined *for evidence of old injuries, incongruity in the joints between* the talus and the malleoli, or a widening of the ankle mortise (Figure 5) Stress *radiography and arthrography are of no great importance* for the diagnosis of the malleolar fractures, even if these examinations sometimes facilitate the diagnosis of a rupture of the deltoid ligament

The purpose of the *treatment* for the malleolar fractures is to bring about as anatomically satisfactory a joint reconstruction as possible to make an essential basis for optimal joint function and to prevent the development of arthrosis deformans Felsenreich (1937) has summarized those factors that favour the development of arthrosis deformans He considers mechanical injuries to the joint cartilage nutritive disturbances *in the joint cartilage traumatically based incongruities*, and disturbances in the cerebrospinal and autonomic innervation *of the joint to be of importance for the development of arthrosis deformans* He particularly emphasizes the importance of non union in ruptures of the deltoid ligament and fractures of the medial malleolus which result in valgus position of the talus with increased strain on the cartilage in the talofibular joint Finally he considers step formation in the articular surface of the tibia, faulty weight bearing and primary mechanical cartilage injuries to be a common combination of causes of arthrosis deformans *after ankle fractures Similar opinions*

*Figure 5 Pronation outward rotation injury of the right ankle (to the left) with a total rupture of the deltoid ligament and all the tibio fibular syndesmosis ligaments The distance between the arrows "la ligne claire (Chaput) is larger in the right ankle*

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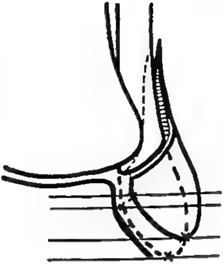


*Figure 6 Supination outward rotation injury with displacement of the distal fibular fragment in outward rotation and in lateral, proximal and dorsal direction ($AB \to A_1B_1$) The displacement makes possible a lateral subluxation of the talus even if the deltoid ligament is not damaged*

*Figure 7 Normal joint function demands the precise fit of the articular ridge of the distal tibia (arrow) into the articular groove of the talus*

factory joint reconstruction (Danis 1949, Hachez-Leblanc 1950, Hohmann 1950, Palmer 1950, 1962, Desenfans & Evrard 1952, Picaud & Poucel 1952, Reimers 1953, Proctor 1954, Sturzenegger 1954, de Marneffe 1955, Vasli 1957, Devlies 1959, Calvetti 1960, Willenegger 1961, Soeur 1963, Willenegger & Weber 1963, Denham 1964, Goltermann 1964, Burwell & Charnley 1965, Weber 1966 Cedell 1967, Gherlinzoni et al 1968, Jansen 1971) During the past 10 years, more and more attention has been paid to the necessity of a careful reconstruction of the injuries of the lateral malleolus, a view advanced by Danis as early as 1949 The operative treatment of malleolar fractures is being adopted by a growing number of surgeons The modern surgeon versed in biomechanics is convinced that only operative treatment can make

possible an anatomically satisfactory reconstruction of a malleolar fracture For purely mechanical reasons, conservative methods very seldom can produce an exact joint reconstruction New observations have proved that even minute rotation and ad latus displacements of lateral malleolar fragments by displacing the vertical axis of the talus give rise to a considerably reduced contact surface between the tibia and the talus (Breitenfelder 1957, Willenegger 1961) Thus the precise fit between the articular ridge of the tibia and the corresponding articular groove of the talus cannot be disturbed without leading to incongruity, dysfunction and arthrosis deformans (Figures 6 and 7)

One frequent cause for failure in conservative methods of treatment is interposition Soft tissue, cartilage and bone fragments can all be interpositioned Fascia, periosteum and ligament tissue are often trapped in the fractures and especially in the fractures of the medial malleolus Even very small pieces of cartilage and bone fragments can prevent an exact reduction, fragments that often are so small or so poorly mineralized that they can scarcely be seen in the roentgenogram In addition, the short ligaments of the ankle often heal defectively because of displacement or interposition of their free portions preventing the normal stabilization of the talus in the ankle mortise

The operative treatment generally suffers from rather few and mild complications providing the surgeon employs a careful preoperative skin treatment and an atraumatic technique of operation Several methods of operative treatment have been published The osteosynthesis devices used vary greatly Postoperative immobilization in plaster is used by some surgeons but is condemned by others Early mobilization after operation has been advocated by Muller (1945), Danis (1949) Rehn (1953), de Marneffe (1955), Willenegger & Weber (1963), Denham (1964) Weber (1966), Gherlinzoni et al (1968) and Jansen (1971) Some surgeons try to restore ankle function by active joint mobilization for a few days or even weeks previous to the aplication of plaster (Hachez Leblanc 1950, Vasli 1957, Burwell & Charnley 1965) Surgeons representing the so called AO group (Willenegger & Weber 1963 Weber 1966) aim at a totally stable joint reconstruction and at a postoperative treatment without immobilization in plaster They assert that plaster is deleterious to the nutrition of the joint cartilage and favours the development of joint stiffness and muscle atrophy They also recommend early walking exercises with tibia condyle-bearing orthoses The principles of the AO-group have been adopted by many

surgeons today, but there are certainly many surgeons who recommend a "softer" view on these problems. They believe that malleolar fractures are suitably treated by fixation or strengthening of the reconstructed injury components by means of a few osteosynthesis devices that are lenient to tissue and fairly small (i.e. cerclage, syndesmosis staple, pins and screws) and by employment of plaster for external fixation. Perhaps "the truth" lies somewhere between these two extremes of opinion. Undoubtedly, large ankle incisions followed by a time-consuming deposition of rather voluminous osteosynthesis devices necessarily favour the development of nutritive injuries to the soft tissue, disturbed healing of the fractures and deep infection. Probably the AO-group is exaggerating the risks of using plaster, which otherwise is known to reduce postoperative pain and enhance the healing of the wound and the sutured ligaments.

Of course not all malleolar fractures should be operated on. Children and elderly people seldom require surgical treatment. Strong indications for operative treatment are present in ligamentous avulsion fragments belonging to the tibia or the fibula, displaced malleolar fragments, and displaced large posterior tibial fragments. Widening of the ankle mortise, i.e. mainly in serious pronation-outward rotation injuries, should be given much attention as they are difficult to manage by conservative methods (Figure 8). As a rule the results of treatment are good provided that the width of the tibiofibular mortise is made normal again. In all probability the low oblique syndesmosis screw should be abandoned because it most often gives too narrow an ankle mortise with accompanying deleterious effects on the joint cartilage. On the other hand, the high syndesmosis screw recommended by the AO-group seems to be a good expedient when it is difficult to make the ankle mortise stable.

Highly comminuted fractures of the articular surface of the distal tibia constitute severe therapeutic problems. Early surgical treatment, including reduction and internal fixation, is the method of choice. However, the frequency of post-traumatic arthrosis deformans is so high that many surgeons recommend a primary arthrodesis.

Is there in fact any proof for the statement that the operative treatment of malleolar fractures is superior to the conservative one? Unfortunately there are very few follow-up materials published where the two methods of treatment have been compared. Most materials are also small and above all very seldom comparable concerning sex and age of the patients and types of injuries. However, a comparison has

*Figure 8 Pronation-outward rotation injury of stage IV with a severe derangement of the joint*

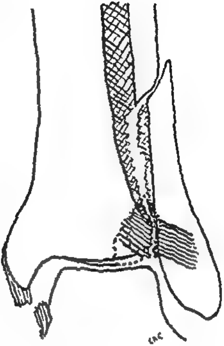

*Table 2 Frequency of arthrosis deformans in supination-outward rotation injuries treated conservatively (Magnusson 1944) and by operation (Cedell 1967)*

| Stage | Frequency of arthrosis deformans | | | |
|---|---|---|---|---|
| | Magnusson's material | | Cedell's material | |
| | No | % | No | % |
| II | 35/118 | (29.7) | 1/38 | (2.6) |
| III | 18/29 | (62.1) | 1/7 | (14.3) |
| IV | 42/53 | (79.2) | 8/34 | (23.5) |
| IV LUX | 9/9 | (100.0) | 13/21 | (61.9) |
| Total | 104/209 | (49.8) | 23/100 | (23.0) |

been made between the results of conservative treatment (Magnusson 1944) and surgical treatment (Cedell 1967) of supination-outward rotation injuries. The length of the follow-up was about [illegible] years. The two materials originated from the same hospital and were comparable concerning sex and age of the patients and distribution of the stage of the injuries. Both materials used the same classification in graduating the

surgeons today, but there are certainly many surgeons who recommend a "softer" view on these problems They believe that malleolar fractures are suitably treated by fixation or strengthening of the reconstructed injury components by means of a few osteosynthesis devices that are lenient to tissue and fairly small (i e cerclage, syndesmosis staple, pins and screws) and by employment of plaster for external fixation Perhaps "the truth" lies somewhere between these two extremes of opinion Undoubtedly, large ankle incisions followed by a time-consuming deposition of rather voluminous osteosynthesis devices necessarily favour the development of nutritive injuries to the soft tissue, disturbed healing of the fractures and deep infection Probably the AO group is exaggerating the risks of using plaster, which otherwise is known to reduce postoperative pain and enhance the healing of the wound and the sutured ligaments

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hanges of arthrosis deformans The frequency of arthrosis deformans f the conservatively treated material was more than twice as large as nt of the surgically treated one (Table 2) There was very good greement among the subjective, the objective and the roentgenolo- ical results of treatment and above all a significant correlation be ween the roentgenological results of treatment and the occurrence of rthrosis deformans

Serious *sequelae* to malleolar fractures, i e grave arthrosis defor mans can be treated very successfully by a fusion of the talo-crural joint Compression arthrodesis according to Charnley (1953) is un doubtedly a very good surgical method The advantages of this method are that it gives rapid and reliable healing and includes a resection of the malleoli and the ligaments which, in other arthrodesis methods, sometimes give rise to residual symptoms even if the tibia and the talus are solidly fused Charnley's ventral approach, however, should be abandoned in favour of the combined lateral and medial approach that leaves the anterior soft tissue undamaged, thus allowing normal blood circulation and normal function of nerves and tendons in the foot

What about *the future* in ankle traumatology? Most of the problems concerning the diagnosis and treatment of ankle injuries have prob ably now been solved The past 5 years have added nothing significant to our knowledge in this field It is doubtful if better osteosynthesis devices can be produced, although we probably can learn more about biomechanical problems A natural evolution in conformity with what has characterized hip and knee surgery would be the introduction of total joint prostheses for the ankle Already today such prostheses are available however, so little experience is at hand that nothing can yet be said about their function and tenability Of course the technical improvement of joint prostheses will proceed even though many ortho- paedic surgeons today do doubt that a total joint replacement in the long run could afford the patient a better situation than an ankle ar throdesis that has healed solidly in good position

## SUMMARY

The author gives an account of the different clinical and roentgenolo- gical methods that are used today in diagnosing ligament injuries and fractures of the ankle Therapeutically the importance of an anatomi cally satisfactory and preferably stable joint reconstruction is empha

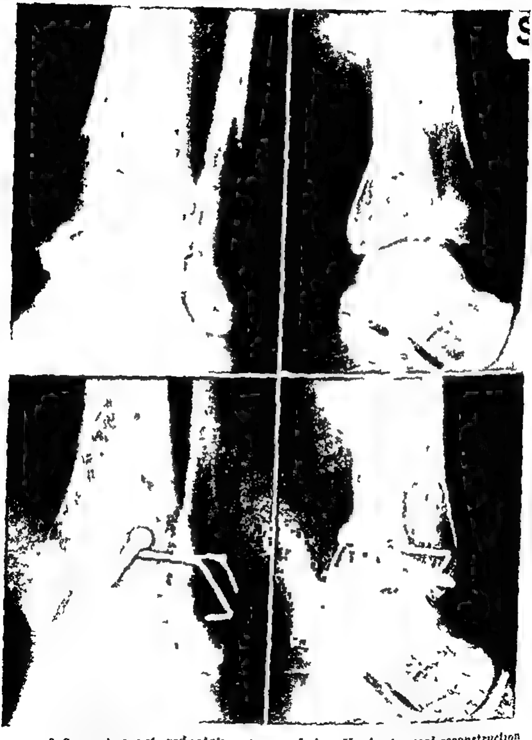


*Figure 9 Supination outward rotation injury of stage IV. Anatomical reconstruction by ligament suture, cerclage, syndesmosis staple and posterior screw*

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sized in order to reduce the frequency of ankle instability and arthrosis deformans Probably most of the problems in ankle traumatology are already solved, however, total joint replacements may become a valuable contribution to our therapeutic arsenal

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sized in order to reduce the frequency of ankle instability and arthrosis deformans Probably most of the problems in ankle traumatology are already solved, however, total joint replacements may become a valuable contribution to our therapeutic arsenal

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*Key words* ankle lesions anterior drawer test, *arthrosis deformans* avulsion

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(Boyes 1970) It consists of 1) Skeletal alignment, 2) Skin cover, 3) Restoration of mobility, 4) Restoration of sensibility, and 5) Restoration of the functional position of the hand in relation to the arm Such are the guidelines which constitute the framework for hand reconstruction They were formulated years ago and are still valid

Within this framework, considerable progress has been made Some advances have resulted from purely technical advances but these alone, although appealing to the surgeon and in themselves important, are not the whole answer In fields such as control of cicatrization, the restoration of gliding planes, or axon regeneration, which at the level of the hand are of great importance, we are only beginning to understand the sequence of biological events The mushrooming of fundamental research in functional anatomy, neurophysiology, biomechanics and biology has already influenced and modified more and more our therapeutic attitudes In particular, the development of new industrial synthetics well tolerated by the organism has opened up some promising new surgical approaches

Of the synthetic materials used in hand surgery, organic silicone has gained increasing importance Silicone rubber implants, which are malleable, resistant and non adherent to surrounding tissues, have found wide application in the restoration of mobility of the fingers

## RECONSTRUCTION OF JOINTS

*For finger joints, resection arthroplasty*, though giving appreciable benefit achieves mobility at the expense of stability Articular prostheses seemed the logical answer The first ones used by Brannon & Klein (1959) and Flatt (1960) were metallic These implants, whose consistency and rigidity were harder than those of the surrounding tissues not being cemented into the bony shaft, often caused wear and resorption of the bone, and even fracture Today, implants totally or partially made of silicone are the most widely employed There are several models which reflect the different biomechanical concepts

For Swanson who, since 1962, has studied the use of implants at various levels in the hand the flexible implant is a dynamic spacer used as an adjunct to resection arthroplasty (Swanson 1973) Stability after arthroplasty depends not only on the implant itself but also on the formation of a new fibrous capsule which develops around the implant (the encapsulation concept)

Niebauer (1971) perfected a flexible implant whose intra osseous

Acta orthop scand 46 446–459, 1975

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# HAND RECONSTRUCTION

RAOUL TUBIANA

The purpose of this review is to highlight the recent advances in reconstruction of the hand If hand surgery has progressed in the course of the last few years, it is due to a combination of factors of which the most important seems to us to be the *individualization of* this field This does not imply a separation of hand surgery from *general reparative surgery,* but rather an adaption of the most recent biological and surgical advances to the needs of this essentially mobile and sensitive organ

Only a few years ago hand reconstruction was confined to the domain of traumatology Now, several new fields have opened, and it is necessary to consider separately at least

- Reconstruction of the traumatic hand
- Reconstruction of congenital malformations
- Reconstruction of the rheumatic hand
- Reconstruction of the paralytic hand

Each *of these subjects could be expanded upon,* but it is not possible to discuss all these topics We would like to consider first the guiding principles of hand reconstruction and then, using selected examples demonstrate the most recent techniques used in the surgery of joints, tendons, nerves and vessels of the hand

For any hand reconstruction, no matter what the aetiology, *one must* establish a therapeutic plan which considers not only the local lesion *but also* the state of the whole limb and of the other hand, and the general condition of the patient The purpose of reconstruction is not so much to restore the anatomy as to restore that function which is the most useful in each case Treatment for one person is not necessarily the same for another, even though their lesions may be similar

Bunnell & Boyes *have summarized in five steps the* plan of repair

disposal For example Kessler (1973) uses a silastic interposition between the metacarpal and the trapezium Swanson totally excises the trapezium and replaces it with an implant plugged into the metacarpal The stability of this new trapezium will depend on the depth of the cavity and the method of repair of the capsule To avoid subluxations, which are not rare, one should reinforce the capsule with a local tendon transfer We prefer the flexor carpi radialis

Caffiniere s prosthesis (1972) consists of a trapezium cup of polyethylene which articulates with a metallic sphere mounted on a metacarpal stem The two pieces are cemented in place before being articulated in the fashion of a total hip prosthesis

The indications for the various types of prostheses are still vague There are some cases where the trapezium has collapsed and the cavity created after removal of the trapezium would be insufficient to assure satisfactory stability of the implant We feel this would be an indication for the Caffiniere's type of prosthesis We have in fact inserted such a prosthesis into the distal extremity of the radius following carpectomy

Thanks to the modern trapezio-metacarpal prostheses, arthrodesis of this joint is now rare Arthroplasties are indicated not only in rheumatoid arthritis and rhizarthrosis but also in cases of post traumatic stiffness or after thumb paralysis We have combined these arthroplasties with pollicization or phalangization of the first metacarpal But these arthroplasties remain inadequate for reestablishing mobility of the first ray, a) in the presence of contracture of the soft tissues of the first web, and b) if there is hypermobility of the metacarpophalangeal joint which interferes with the reeduction of the proximal arthroplasty

Stabilising the M P joint by capsular repair or arthrodesis combined with freeing of the soft tissues is indispensable for a good result All stages can be completed at one operation if there is adequate skin cover, but it often is preferable to separate these steps

*For the carpus,* Swanson has designed silicone implants to replace the scaphoid and lunate These implants, which act as "spacers", are well tolerated biologically and mechanically *Their stability depends* on the reconstruction of a strong capsule They must be implanted before the arthrosis has involved too many carpal and radio carpal joints In cases of simultaneous lesions of the scaphoid and lunate, Michon (1973) has developed a scapho lunate monoblock implant

*At the radio carpal joint,* we have embarked upon wrist arthroplasty with considerable reluctance because we know the importance of

shafts are covered with Dacron The surrounding tissue infiltrates into the Dacron mesh, thus fixing the extremities

Calnan & Reis (1968) studied a polypropylene implant with a particularly thin hinge designed to diminish resistance Nicolle (1973) added a silicone capsule to prevent invasion of fibrous tissue around the joint mechanism

Finally it was logical to apply to the hand the experiences gained from joint prostheses in the lower limb Arthroplasties were developed along the lines of the Charnley low friction arthroplasty principle using metal against polyethylene joint surfaces, and stem fixation with cement This solution was adopted by Stellbrink (1968) for the fingers (St George Prosthesis) The principle is probably most suitable for the more complex joints, such as the first carpo metacarpal or the radio carpal ones, as will be mentioned later

This review will not cover the technique of fixation of these implants nor give a detailed analysis of the results We refer to statistics already published (in particular, Swanson 1973 and Bedeschi & Luppino 1974)

In my experience, the Swanson type prosthesis which we have used since 1968 is most useful for suppressing pain in rheumatoid arthritis at the M P and I P P joints Correction of deformity depends more on the musculo-tendinous balance one obtains than on the implant itself Stability depends on the technique used we construct a lateral collateral ligament at the M P and I P P joint levels of the index and middle finger to resist the pressure of the thumb Recovery of mobility is more unpredictable than relief from pain and depends on the state of the motor muscles, early physiotherapy and patient's determination Complications, so far, have been few Early dislocations and fractures of the prostheses are related to technical errors of insertion or to excessive stress by the patient, especially in heavy people using elbow crutches Because the stems of Swanson's finger implants remain loose in the shafts, the risk of fracture is reduced, and their removal and replacement, if required, is a fairly simple procedure However, it is becoming evident that the incidence of fractures is increasing with time

Results of implants after traumatic lesions seem to be less favourable, probably because of the associated scar tissue Their use for M P replacement in stiffness after burns or interosseous paralysis is a last resort

*For the trapezo metacarpal joint* we have several prostheses at our

attempt to impede these normal adhesions will interfere with the physiological repair (Potenza 1964, Lindsay 1960) However, one must ensure that no excessive adhesions result from the traumatic surgical repair

Movement of the repaired tendon is facilitated by a remodelling of the scar tissue, but we do not understand the mechanism of this process It is difficult to explain why the scar adjoining the tendon ends remains solid and yet the peripheral scar adhesions become soft and allow movement To understand this phenomenon a more intimate knowledge of the processes of synthesis, maturation and degradation of collagen is required Research is in progress to study the factors capable of influencing this cycle so that they can be controlled pharmacologically Several such investigations have been undertaken and results in clinical applications already are encouraging (Peacock & Madden 1969, Bora 1972)

The long standing division between the advocates of primary and secondary repair belongs now to the past No longer is there a basic objection to primary tendon repair as a concept *Primary repair*, as Verdan has shown since 1952, can often be performed even in the so-called 'no man's land" provided that the technique is meticulous and precise and the local conditions acceptable Advances have been made in both primary and secondary repair In primary flexor tendon repair, no longer is routine excision of the superficialis tendon advocated Its ablation inevitably tears the mesotendon and interferes with the vascularization At present we have become more conservative, preserving both profondus and superficialis tendons when possible (Verdan & Crawford 1971) and limiting the excision of the fibrous sheath, which is of considerable importance mechanically Kleinert (1975) has developed a technique of primary tendon suture using a protective splint which allows early passive mobilization

*With regard to secondary repair*, preserved tendon grafts have been under investigation for a long time and enable us to have tendon banks

Iselin et al (1963) developed the use of acellular grafts preserved in a mercurial solution of cialit Seiffert & Schmit (1971), using labelled isotopes showed their progressive substitution by collagen

For many years Peacock has experimented with flexor tendon transplants using gliding appendages taken from fresh cadavers This method has been used successfully in humans (Peacock & Madden 1967, Hueston et al 1967) and one can now envisage human composite flexor tendon allografts

stability at this joint, the most proximal in the hand This is why arthrodesis has been done so frequently, especially for post traumatic lesions The functional results are satisfactory in unilateral lesions provided that the muscles of the forearm are little disturbed It is different if the extrinsic muscles of the hand are insufficient or contracted because of scarring ischaemia or paralysis Preserving flexion and extension of the wrist reinforces the action of the muscles spanning the joint and so results in an active tenodesis Stiffness of the wrist is a serious handicap when bilateral, especially in extension, because the patient is not able to attend to toilet functions Bilateral wrist lesions are frequent in rheumatoid arthritis and it is especially in these patients that arthroplasties have been performed

Various types of prostheses have been proposed and probably have different indications The most ambitious types envisage recovery of flexion, extension and even lateral movement (Meuli 1973, Gschwend & Scheir 1973) Swanson uses a flexible silicone implant whose stems slot into the radius and third metacarpal, while Jackson (1975) advocates an interposition arthroplasty using a 3 mm thick silicone disc This is inserted between the joint surfaces of the radius and the carpus There is minimal bony resection and the results are encouraging regarding patients afflicted with rheumatoid arthritis in whom one is anxious to relieve pain and preserve some active mobility

Many other models of joint implants are under study The best anatomical replicas are not, of necessity, the most useful It is probable that no definite prosthesis has yet been found, and thanks to biomechanical research and its clinical applications, all current models will be modified with time

The restoration of mobility at various levels in the hand requires not only mobile and stable joints, but also active motor muscles and the recreation of gliding planes so that the tendons may move

## REPAIR OF TENDONS

Tendon repair is one of the most common and yet one of the most deceiving surgical operations in the hand Only by thoroughly understanding the healing mechanism of tendons is one able to obtain satisfactory results of repair In the past few years, thanks to the electron microscope, it has been shown that the invasion of fibroblasts comes from the periphery, and not from the extremity of the tendons as was previously thought Adhesions are therefore inevitable and any

Microsurgery of the upper limb is used in three capacities 1) microneural surgery, 2) microvascular surgery and 3) microlymphatic surgery

*1) Microneural surgery*

Unreliable and generally disappointing results of peripheral nerve surgery led logically to attempting more accurate alignment of the nerves component parts Each nerve consists of an outer fibrous sheath (epineurium) which encases fasciculi or bundles of nerve fibres Each fasciculus is encased in its own sheath of perineurium and contains, on an average, 10,000 myelinated and unmyelinated axons, all of which are embedded in an interstitium of connective tissue called the endoneurium It is obviously fallacious to expect to be able to align each of the component parts, for indeed the median nerve in the forearm contains 20–40 funiculi and the ulnar about 20 This means that almost half a million axons are present in the median nerve

The microscope has enabled us, however, to progress one step further anatomically and permits accurate alignment and suture of, in some cases, individual fasciculi, but mostly of groups of fasciculi The groups are matched according to shape, size and number of fasciculi within the group

Blood vessels in the epineurium are a further aid to orientation, especially in primary repair as is the mesoneurium A *knowledge of cartography* is important for this accurate alignment because, stated negatively pairing a motor with a sensory fascicule guarantees failure *Millesi et al* (1972) have shown that the scar tissue of a neuroma is derived from the damaged epineurium To prevent this he advocates stripping the epineurium away from the suture line and minimum sutures (one stitch per fasciculus or group of fasciculi) He has convincingly shown that tension at the suture line causes scar formation This results in a mechanical block to the passage of axons The value of temporary joint flexion in overcoming tension is of short duration because secondary *scar formation* develops once normal posture is resumed and this causes constriction and even division of the axons To prevent tension the *only* satisfactory solution is the *nerve graft*

Axons grow through two anastamoses without tension more readily than through one with tension With the arm in the neutral position a gap of greater than 2 5 cm after the *nerve ends* have been dissected free requires grafting (Millesi 1972)

Other easier methods have been perfected to reestablish planes of gliding. Years ago, experiments were carried on to build up gliding canals for tendons, by *inclusions of foreign bodies of glass* or *metallic rods* (Mayer & Ransohoff 1936). On the biological plane these attempts have been a failure because of the foreign body reaction, which merely exacerbated the formation of new collagen with its associated detrimental effects on tendon gliding. With the introduction of the almost inert newer substances such as silicone, the problem has been reconsidered (Carroll & Bassett 1963). Hunter (1965, 1971) proposed the principle of forming a new tendon sheath in response to a gliding tendon prosthesis (stage one) followed by the tendon grafting (stage two). This implant is fixed at the level of the distal extremity and pulleys should be constructed at the required levels without fear of adhesion formation. The great advantage of this technique is the creation of a tunnel which at the second stage of the procedure is not *reentered except at its proximal and distal extremities*. This is the favoured method of tendon grafting in less than optimum cases. It can also prepare the bed for tendon transfers when there is considerable scarring.

One cannot enlarge here on tendon transfers, a subject which has been particularly brought to our attention over the last few years (Tubiana 1969, 1974). However, one should be aware of the many types of tendon and muscle transfers, tenodeses and capsulodeses devised by Zancoli (1968), Littler (1964), Brand (1974), Riordan (1974) and Parkes (1973) which have enabled innumerable paralysed hands to be rehabilitated.

## MICROSURGICAL TECHNIQUES

Meticulous technique is paramount if one expects satisfactory results in surgery. To this end, magnification is not an admission of blindness but the acceptance that if you can see what you are doing you have a better chance of doing it well. Thus, low power magnification with loupes is now a mandatory tool in the hand surgeon's armamentarium. It aids accurate atraumatic handling of tendons and other tissues.

Although the advantage of the microscope in surgery has been appreciated *for many years, first by otolaryngologists* and later by neurosurgeons, its use in peripheral nerve and hand surgery is a very recent phenomenon (Smith 1964).

It has opened the door to a fascinating new world which has caught the imagination of surgeons everywhere.

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*1) Microneural surgery*

Unreliable and generally disappointing results of peripheral nerve surgery led logically to attempting more accurate alignment of the nerves component parts Each nerve consists of an outer fibrous sheath (epineurium) which encases fasciculi or bundles of nerve fibres Each fasciculus is encased in its own sheath of perineurium and contains, on an average, 10 000 myelinated and unmyelinated axons, all of which are embedded in an interstitium of connective tissue called the endoneurium It is obviously fallacious to expect to be able to align each of the component parts, for indeed the median nerve in the forearm contains 20–40 funiculi and the ulnar about 20 This means that almost half a million axons are present in the median nerve

The microscope has enabled us, however, to progress *one step* further anatomically and permits accurate alignment and suture of, in some cases individual fasciculi but mostly of groups of fasciculi The groups are matched according to shape size and number of fasciculi within the group

Blood vessels in the epineurium are a further aid to orientation especially in primary repair as is the mesoneurium A knowledge of cartography is *important for this* accurate alignment because, stated negatively pairing a motor with a sensory fascicule guarantees failure Millesi *et al* (1972) have shown that the scar tissue of a *neuroma* is derived *from* the damaged epineurium To prevent this he advocates stripping the epineurium away from the suture line and minimum sutures (one stitch per fasciculus or *group of fasciculi*) He has convincingly shown that tension at the suture line causes scar formation This results in a mechanical block to the passage of axons The value of temporary *joint flexion* in overcoming tension is of short duration because secondary scar formation develops *once* normal posture is resumed and this causes constriction and even division of the axons To prevent tension the only satisfactory solution is the nerve graft

Axons grow through two anastomoses without tension more readily than through one with *tension* With the arm in the neutral position a gap of greater than 2.5 cm after the nerve ends have been dissected free requires grafting (Millesi 1972)

Other easier methods have been perfected to reestablish planes of gliding. Years ago, experiments were carried on to build up gliding canals for tendons, by inclusions of foreign bodies of glass or metallic rods (Mayer & Ransohoff 1936). On the biological plane these attempts have been a failure because of the foreign body reaction, which merely exacerbated the formation of new collagen with its associated detrimental effects on tendon gliding. With the introduction of the almost inert newer substances such as silicone, the problem has been reconsidered (Carroll & Bassett 1963). Hunter (1965, 1971) proposed the principle of forming a new tendon sheath in response to a gliding tendon prosthesis (stage one) followed by the tendon grafting (stage two). This implant is fixed at the level of the distal extremity and pulleys should be constructed at the required levels without fear of adhesion formation. The great advantage of this technique is the creation of a tunnel which at the second stage of the procedure is not reentered except at its proximal and distal extremities. This is the favoured method of tendon grafting in less than optimum cases. It can also prepare the bed for tendon transfers when there is considerable scarring.

One cannot enlarge here on tendon transfers, a subject which has been particularly brought to our attention over the last few years (Tubiana 1969, 1974). However, one should be aware of the many types of tendon and muscle transfers, tenodeses and capsulodeses devised by Zancolli (1968), Littler (1964), Brand (1974), Riordan (1974) and Parkes (1973) which have enabled innumerable paralysed hands to be rehabilitated.

## MICROSURGICAL TECHNIQUES

Meticulous technique is paramount if one expects satisfactory results in surgery. To this end, magnification is not an admission of blindness but the acceptance that if you can see what you are doing you have a better chance of doing it well. Thus, low power magnification with loupes is now a mandatory tool in the hand surgeon's armamentarium. It aids accurate atraumatic handling of tendons and other tissues.

Although the advantage of the microscope in surgery has been appreciated for many years, first by otolaryngologists and later by neurosurgeons, its use in peripheral nerve and hand surgery is a very recent phenomenon (Smith 1964).

It has opened the door to a fascinating new world which has caught the imagination of surgeons everywhere.

China, Japan and Australia (O Brien & Miller 1973, Lendvay & Owen 1970)

Initially, reimplantation of amputations of all fingers were attempted with varying degrees of success Avulsion and severe crush injuries had universally poor results

It is generally accepted that *primary repair* of all structures is preferable (one artery and two veins, nerves, tendons and bone), since any secondary surgery may well impair the vascular supply The bone is shortened slightly The patient is heparinized for 2 weeks, by which time collateral venous circulation is well established (Chinese Medical Journal) and the digit can survive permanently

The long term prognosis is not clearly defined, but return of sensation has been surprisingly good In a series of 61 digits (O Brien, MacLeod & Morrison, personal communication) none had neuroma problems, all had protective sensation and the two-point discrimination ranged between 3 and 10 mm When a joint is damaged, movement obviously will be permanently impaired Tendon movement has been reasonably good

After many man hours spent, after several failures, after a more careful balance between the anaesthetic risk, the time spent in hospital and the real benefit for the patient, a new, much less enthusiastic pattern of indications seems to emerge for the reimplantation of fingers

The reimplantation of the thumb remains a major indication, so are multiple amputations, especially the ones of the guillotine type, which have a better chance of success Lesser indications are the reimplantation of the single amputated index finger, reimplantation of single digits in children reimplantations for cosmetic reasons

Reimplantation of hands is most worthwhile, with excellent return of sensory function and although motor return is often poor (combination of poor nerve regeneration and ischaemic muscle), tendon transfers can complement this deficiency Amputations more proximal have not been a great success because of their greater muscle content and the greater distance that must be travelled in nerve regeneration

*B Chronic ischaemia* Many hands have become functionally poor because of poor blood supply (post traumatic) Although viable, they are constantly plagued by cold and paraesthesia Arteriograms may demonstrate a cause that can be remedied, and vein grafts can be used to bridge large arterial defects

*C Venous insufficiency* In the classical ring finger degloving injury

Finally, magnification is of great benefit wherever interfascicular neurolysis is considered necessary With magnification and the new techniques of nerve suture and grafting, renewed interest has been directed to the surgery of brachial plexus lesions previously considered hopeless Narakas (1972), Samii (1975) and Millesi et al (1973) report some encouraging results

*2) Microvascular surgery*

*A Replantation* For centuries the dream of replantation of tissues had remained mythology until the almost fairy-tale reports of limb and digital reimplantation from China reached the outside world This stimulated much research into the technique of suture of small vessels (Buncke & Murray 1971) and some sporadic reports of clinical replantation appeared (arm· Malt & McKhann 1964), (digit Tamai 1968).

It is now possible to obtain consistently high patency rates following anastomosis of vessels as small as 0 5 mm in diameter The exact technique is debated, but in essence it involves resecting the vessel ends back to normal tissue, peeling back the filmy periadventitial tissue and irrigating with heparinized saline, taking extreme care not to damage the intimal lining In some circumstances gentle dilatation of the lumen with blunt-nosed jeweler's forceps is advantageous especially if the vessel is in spasm The vessels are then approximated by the use of a double clamp and sutured together, usually by the 120° triangulating technique using 10 0 or finer round bodied nylon monofilament suture A vessel of 0 7 mm diameter will usually require 6–8 interrupted sutures Before the release of the clamps the anastomosis is temporarily wrapped in a plastic strip to prevent excessive blood loss Blood is also a potent cause of spasm Various topical and systemic agents have been used to prevent platelet coagulation at the anastomosis site Whether they are of practical value clinically is difficult to prove The technique of venous anastomosis is essentially the same, except that veins have much thinner walls, are usually larger, require more sutures and collapse, with the resultant danger of catching the posterior wall with the anterior stitch Immersing the vessel in water will often float the walls apart and facilitate suturing Interposition vein grafts solve the problem of the artery whose ends are too far apart to anastomose

Replantation of digits became the kindergarden training ground for microsurgeons and large series were soon documented, especially in

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collaboration between the laboratory and the operating theatre It is worthwhile creating hand centres not only for the benefit of patients but also for research and for training surgeons These centres must become places of collaboration between numerous clinical and preclinical specialities namely orthopaedics, traumatology, plastic surgery, rheumatology, neurology, physiotherapy, and applicance makers, as well as biologists and anatomists, all applied to the reconstruction of the hand

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Is [illegible]
Is [illegible]
[illegible] tendon [illegible] *Plast Reconstr Surg* 32 401–413

where the skin has not been completely avulsed, the situation is often that the arteries are intact but the venous drainage has been completely cut off. The skin envelope of the finger becomes turgid with congested blood, and unless venous anastomosis is *performed*, retrograde arterial obstruction will occur with resultant loss of the finger.

*D. Free flaps.* Large tissue defects of the arm and hand requiring flaps can be covered by free flap transfer using microvascular anastomosis. This avoids prolonged immobilization in a position deleterious to hand function. It enables immediate post operative elevation, physiotherapy and avoids secondary operations.

Sensory free flaps can be used to reinnervate areas of the hand. The usual donor sites are the first and second web spaces of the foot.

Reconstruction of the congenital and traumatic hand may be managed by toe to thumb or digital transfer.

Free innervated muscle transplant may be used to activate the arm.

### *3. Microlymphatic surgery*

Although in its infancy, microlymphatic surgery is now able to achieve a high rate of long term patency of lymphovenous anastomoses in dogs (Gilbert 1975). One clinical case of lymphoedema of the arm has been reported in which lymphovenous anastomosis was done with dramatic results (Sykes & O'Brien, personal communication).

In summary, microsurgery has opened new prospects in the field of hand surgery by the developments in neuro, vascular and lymphatic surgery. The final perspective in terms of justifiable operating time indications and results are not yet entirely clear.

## SUMMARY

To conclude, one must apologize for having introduced so many subjects and left so many loose ends. Hand reconstruction poses a multitude of problems which are presently in an evolutionary phase. In discussing the notion of hand surgery specialization one draws upon orthopaedic, plastic and microsurgical techniques. But is it not precisely this adaption of diverse techniques to one organ which constitutes a speciality?

Rapid progress in hand surgery was achieved the moment surgeons confined the major part of their activities to the treatment of this organ. But let us repeat that progress implies collaboration and not isolation. Advances highlighted in this review resulted mostly from

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## INJURIOUS FORCES

In terms of accidental injury the body may be damaged by impact (which includes compression) by twisting or by distraction In the case of road accidents impact is much the most frequent primary force causing injury although the effect of impact upon movable and deformable structures such as the foot or the soft parts of the limbs or trunk include shearing twisting and distraction

## PATTERNS OF INJURY

Many of the effects of road accidents upon the human body have characteristic patterns which may include the association of an obvious injury with a much less obvious but possibly more severe one Specific examples are fracture of the shaft of the femur which distracts attention from an accompanying dislocation of the hip and fracture of the lower part of the legs masking an injury of the foot In each case the swellings of the two injuries are continuous and may not be recognized as having separate sources

The patterns of injury vary according to whether the person is struck by a vehicle or is inside it and if he is inside it the patterns vary according to whether he is restrained or free to move and whether or not the vehicle is deformed Knowing the circumstances may put the examiner on his guard and cause him to look with particular care to see whether or not certain likely injuries have in fact been inflicted The more detail that can be obtained from witnesses rescuers or the victims, the better equipped the examiner will be to avoid making mistakes Failure in diagnosis in cases of multiple injuries often occurs because the injured person is examined to find out what his injuries are rather than to confirm or exclude those that could well be present Pedestrians are usually thrown up in the air and land on the bonnet of the vehicle if they are struck low down or are thrown forwards and to the ground to suffer further injury if they are struck higher up The resulting injuries are usually mainly if not entirely on one side of the body Figure 1)

### *Motorists*

The injuries typical of the unrestrained occupant of a motor vehicle are too well known to warrant more than a mention (Figure 2) but the injuries caused by means of restraint deserve attention

Acta orthop scand 46, 460–474, 1975

The Birmingham Accident Hospital, Birmingham, England

# CLINICAL ASPECTS OF THE DISRUPTIVE EFFECTS OF ROAD ACCIDENTS ON THE HUMAN BODY

P. S London

A great deal of detailed study has been made of the interaction of forces generated by accidental violence and the damaging effects of impact on motor vehicles and their occupants One of the beneficial results has been the identification of shortcomings in the design and construction of motor cars and the protective devices installed in them An understanding of the strength of materials is an obviously important part of the science of structural engineering, and application of engineering methods to the human body has led to greatly improved understanding of how best to design both implants and external appliances It has also enhanced respect for what can truly be referred to as the marvels of the human body

The clinician has much to thank his engineering colleagues for, but it is fair to say that even if he is largely lacking in mathematical ability and knowledge of engineering the accident surgeon has at his disposal a vast store of information about the body's ability to withstand violence and even more about the way in which violence damages it Careful examination of the injured part by inspection, palpation, manipulation and surgical exploration is particularly useful when combined with knowledge of how the injury occurred An accurate account of the nature, direction and amount of force applied can explain the anatomical damage so well that when a similar pattern of anatomical damage is seen on another occasion the circumstances of injury can be correctly inferred

Alternatively, accurate knowledge of how the force was applied may warn the accident surgeon of damage that may be hidden within the depths of the body As an animal leaves its spoor, so can accidental violence declare its nature by the traces of its application

*Injuries resulting from restraint* Gissane & Bull (1968) found that in 50 persons injured and 13 killed while wearing seat belts there was no case in which a correctly fitted and correctly adjusted belt of approved design had inflicted serious injury Eastwood (1972) has recorded rupture of the breast by the oblique band of a two band restrainer but the price of effectual restraint is usually not more than a slightly sore chest or shoulder On the other hand there have been many instances of injury caused by lap belts that have crossed the belly instead of the pelvis (Friedman et al 1969 Williams & Kirkpatrick 1971 Towne & Coe 1971)

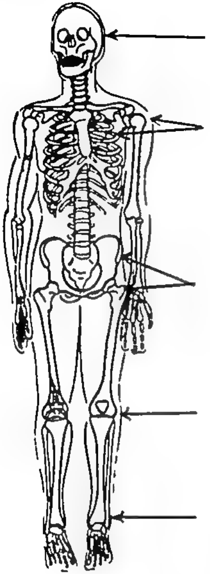
It has been suggested that if the body is held firmly in place in a crash the head and neck will be flexed with increased violence and consequently be more vulnerable than if the body could move forwards as well It is certainly the case that the chin can strike the sternum with sufficient force to fracture it and even to rupture the underlying heart but this requires the much greater violence of an aircraft crash (Mason 1973)

*Injuries caused by deformation* include decapitation and severance of limbs instantly fatal crushing and trapping usually by the lower limbs either by displacement of the dashboard or by displacement of the floor and pedals

Inversion (supination) is the most frequent cause of injury in the foot not because it is the most violent force to which the foot is subjected but because this is the movement most easily produced by ordinary variations of everyday forces It causes such injuries as tearing of the lateral ligament of the ankle or avulsion of the base of the fifth metatarsal bone but some of the most interesting and severe injuries can be regarded as being caused by impact upon the inverted foot Figure 3 shows an injury of this type in which the foot was broken by violent inversion that destructively accentuated the longitudinal arches

Among the effects of such violence are total dislocation of the talus fracture of the neck of the talus with anterolateral displacement of the body of the bone talocalcaneonavicular dislocation and midtarsal fracture subluxation in which the navicular swings with the distal bones into adduction round the head of the talus against which it is pressed with such force that as the bony surfaces in contact are reduced in area they give way so that the two bones show mutual indentation (Figure 4) The signs of lateral distraction are often obvious in these injuries

*Figure 1 Sites of injury in pedestrians struck by motor vehicles*



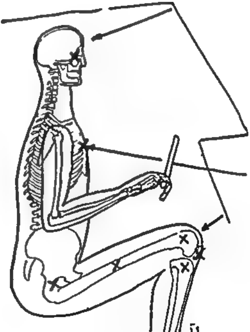


*Figure 2 Sites of injury in unrestrained drivers of motor vehicles*

*Figure 3 b*

are displaced dorsad or in a plantar direction from the talus, but these injuries are *more likely to follow* falls than road accidents

*The ankle* The apparent paradox that whereas the most frequent injury of the foot is by *inversion* the most frequent fracture of the ankle is the result of *lateral rotation of the talus* within the mortice is resolved by the phenomenon of *torque conversion* In spite of its anatomical complexity the talocalcaneonavicular joint can be regarded as having a straight axis *of movement* that runs *obliquely* upwards and medially Thus, when the foot is *inverted* while the weight of the body is on it, the obliquity *of the* axis of movement results in an outward

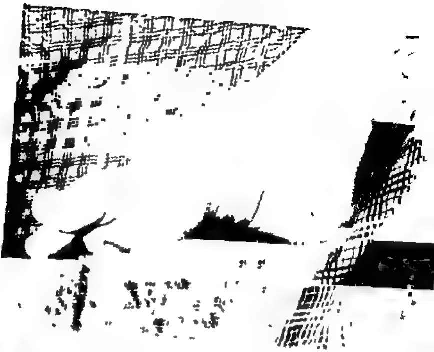


*Figure 3 a*

*Figure 3 This foot was trapped and crushed by deformation of the floor of the driver's compartment*

Eversion of the foot is a less frequent cause of injury and usually leads to tarsometatarsal disruption. Both the shape of the foot and its radiological appearance are characteristic (Figure 5) but the significance of these signs may not be recognized

Occasionally the navicular and a greater or lesser part of the foot


*Figure 3 b*

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*Figure 4 Mutual indentation of talus and the navicular bone*

*Figure 5 Deformity and swelling caused by an eversion injury a, external and b, radiological appearance*

B

counterthrust of the talus on the lateral malleolus This phenomenon has been clearly described by Hicks (1953) and is implicit in classifications of fracture subluxations of the ankle (Ashurst & Bromer 1922 Hansen 1942)

## IMPACT ON A YIELDING STRUCTURE

*The head*

It is well known that a blow on the head is much more likely to cause commotio cerebri if the head is free to move than if it is fixed (Denny Brown & Russell 1941, Holbourn 1943 Pudenz & Sheldon 1946 Gudjian & Lissner 1961) but it is perhaps less well known that a blow on the head can lead to serious injury of the neck with no more than a faint graze or bruise at the place of impact (Figure 6) This is usually on the face or forehead and is associated with hyperextension injury of the neck which may have no demonstrable bony component and is liable to be unrecognized particularly in an unconscious patient It is necessary to bear this possibility in mind and to supplement careful radiological examination with a careful search for clinical evidence of damage to the spinal cord and nerve roots which is more likely to occur in persons with cervical spondylosis

The converse action occurs when impact on the rear of a motor car sets the body suddenly in forward motion relative to the head but these injuries are usually more painful than serious

*Figure 6 The frontal graze resulting from a fall and accompanied by an extension fracture of the neck*

*Figure 4 Mutual indentation of talus and the navicular bone*

*Figure 5 Deformity and swelling caused by an eversion injury*
*a external and*
*b radiological appearance*

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The converse action occurs when impact on the rear of a motor car sets the body suddenly in forward motion relative to the head, but these injuries are usually more painful than serious

*Figure 6 The frontal graze resulting from a fall and accompanied by an extension fracture of the neck*

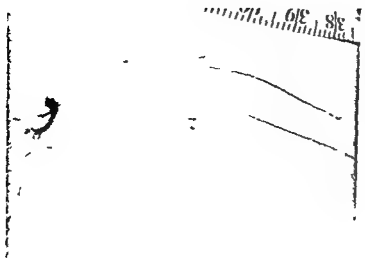


*Figure 7 Bruising stamped onto the abdominal wall and accompanied by rupture of the spleen and haematoma of the mesocolon*

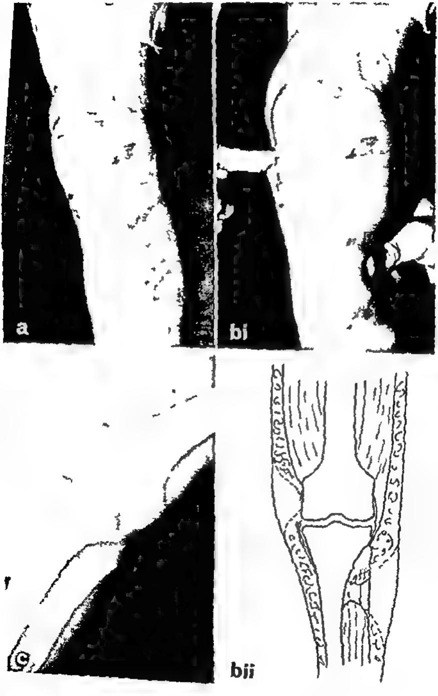
*The soft tissues*

*Closed injuries* A blow on the belly wall when it is relaxed can drive it back against the spine, where the crushing effect can transect structures in the abdominal wall or within the abdominal cavity In such cases there may be the tell-tale marks of bruising with the pattern of clothing (Figure 7) These marks have also been found on the neck as external evidence of rupture of the trachea In other parts of the body a forcible blow can crush muscles and vessels against bone, destroying both The injury may appear to be no more than a large bruise but if it is palpated firmly it will be found that the skin can be impressed until it comes up against bone (Figure 8)

Another result of impact on soft tissues occurs when a limb is run over by a rubber-tyred wheel The crushing effect of the wheel tears the soft parts away from one another and may tear them from their attachment to bone this disruption is aggravated by the fact that the tyre grips the skin and tears it from its deep attachments (Figure 9)

*Open injuries* Pare was aware that alterations in posture after a penetrating injury could lead to the staggering of holes in different layers so that there was no longer direct access to anything embedded

*Figure 8 a The external appearance of a leg had been struck by a motor vehicle*
*Figure 8 b Rupture of the medial ligament of the knee and transection of the extensor muscles by crushing made it possible to indent the skin through the haematoma until the bare bone of the femur and of the tibia could be clearly felt*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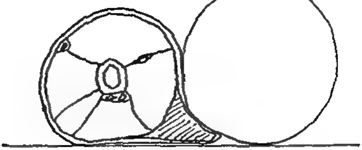


*Figure 9 a As the tyre reaches the skin it drags it from the deep fascia over much of the circumference of the limb*

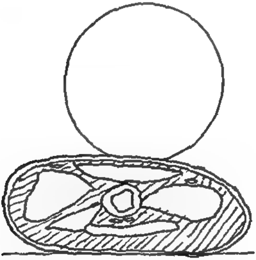


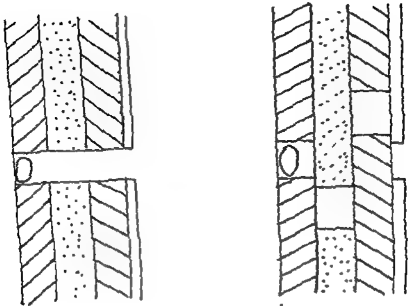
*Figure 9 b As the wheel passes over the limb all the connective tissue planes are torn open, leaving spaces that accommodate large quantities of blood if the skin does not split open*

in the wound (Figure 10) (Keynes 1951) This should be borne in mind when exploring penetrating wounds

## STABILITY OF FRACTURES AND DIAGNOSTIC MANIPULATION

The concept of stability and instability of fractures is well established but it should be recognized that a fracture may be stable either in deformity or after deformity has been corrected

When a fracture is to be manipulated, what the manipulator should



a b

*Figure 10 a At the moment of injury the track of penetration is straight, but an alteration of posture can shift the layers of the injured part (b)*

try to find out is not the best position that can be achieved but the best position that can be maintained by simple means

Diagnostic manipulation will enable the surgeon to decide whether or not the fracture will be stable in an acceptable position without recourse to traction or to internal fixation. The first step is to try to pull the fragments into line and, having done so, to push them together to find out how easily they slip and overlap once more Fracture 11a would resist shortening, whereas fracture 11b would not Traction alone is not always enough, especially when the fracture is transverse and has become overlapped without losing its periosteal hinge In such a case, the correct action is to bend the fracture and then to move the distal fragment until it comes edge to edge with the proximal fragment, with which it is then aligned (Figure 12) A further diagnostic manipulation will enable the surgeon to decide whether or not the end to end contact is adequate The fragments are pushed firmly together and rocked to see how easily this movement can be brought about both backwards and forwards and from side to side (Figure 13).

Diagnostic manipulation will often enable the manipulator to decide

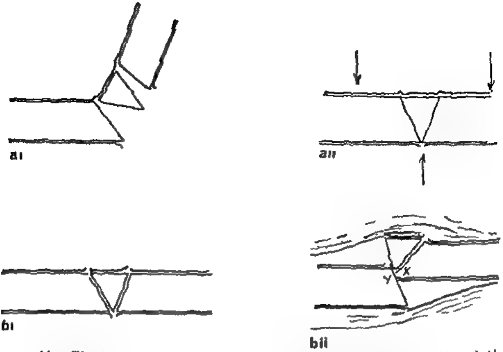



*Figure 11 a The fracture has a hinge of soft tissue that makes it possible to hold it accurately in place by using 3 point fixation as shown by aii*
*Figure 11 b The hinge has been broken and the fracture will be stable only when displaced enough to tighten the more distant soft tissues or to engage point x in the marrow cavity at y*

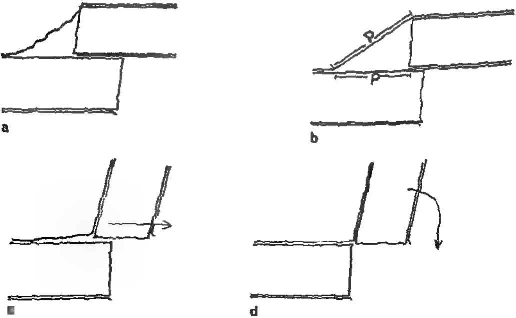



*Figure 12 a b Traction alone will not bring end to end the fragments of a transverse fracture with a hinge*
*Figure 12 c d The fracture has first to be bent to slacken the hinge*

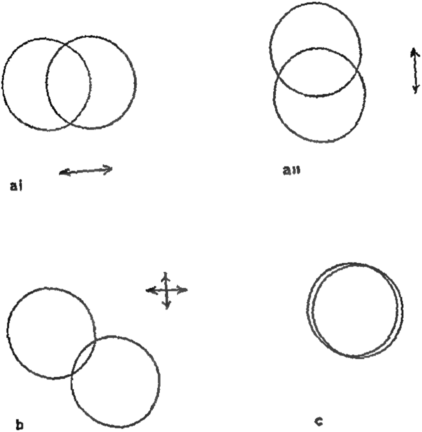



*Figure 13 According to the areas in contact transverse fractures can be recognised by feel as being easily rocked in one direction (a) both directions (b) or neither direction (c)*

whether or not operation is needed and if it is not whether an acceptable degree of correction can be achieved When it is combined with what x rays show and what operating on a fracture reveals diagnostic manipulation becomes increasingly informative and reliable as a guide to treatment It also helps the experienced manipulator to cut down the amount of diagnostic radiographs needed to guide him

## SUMMARY

Knowledge of the patterns of injury from road accidents helps to reduce the risk of diagnostic error through oversight

Understanding the patterns of disruption of the body gives surgeons a better understanding of the nature of the injury and of the behaviour of the injured tissues This is of particular value in the diagnostic manipulation of fractures to decide whether they need internal fixation or whether external splintage will keep them in an acceptable position

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*Key words* patterns of injury disruption of soft tissues stability of fractures *diagnostic manipulation*

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Acta orthop scand 46 475–483, 1975

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# INJURY PATTERNS IN TRAFFIC ACCIDENTS AND SUGGESTED PREVENTIVE MEASURES

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The increasing motorization of recent decades has resulted in increasing numbers of road accidents An attempt must be made to reduce the numbers and effects of accidents The task of traumatological research is not and cannot be the prevention of accidents, but rather to investigate in collaboration with technologists, the question of how injuries in road traffic accidents can be prevented or reduced It is car occupants, however, who have received most attention in research projects These efforts received great support from the American National Traffic Safety Act of 1966 Since then there has been a revolution in what is called the inner safety of vehicle construction, a development which is certainly not yet concluded

The first result of the American legislation that was obvious even to the layman was brought about by the ordinance concerning safety locks in vehicle doors While up to 1966 in Sweden about 35 per cent of occupant fatalities in vehicle accidents were the result of ejection, today in modern cars this is a rare occurrence

The car maker needs data on the tolerance of the human body in order to improve his vehicles, he has to know how the different injuries arise and thus which parts of the vehicles are to be regarded as being particularly dangerous Attempts have been made to ascertain the necessary facts by analysing traffic accidents in detail and correlating the victims injuries with the damages to the vehicles In addition comprehensive statistical evaluations were made of the data arrived at by investigating traffic accidents Through experiments carried out on cadavers, attempts were made to determine the tolerances of certain regions of the body to dynamic loads, the main interest being centred on the skeleton By means of collision experiments with living test persons or human cadavers, attempts were made to determine the course of movement and the tolerances of the human

body, this was after the realization that the dummy, however sophisticated it may be, is only a poor substitute for the human body.

Today much is known concerning the skeleton's tolerance to dynamic and static loads, while our knowledge about the tolerances of the soft parts is limited. In an accident situation, certain injury patterns may be expected, as will be briefly shown in the following.

## OCCUPANTS OF PASSENGER VEHICLES

### *Head-on collision*

*Driver.* As far as the second collision is concerned, i.e. the impact of a driver not protected by a restraint system, it is decisive whether the front part of the vehicle is raised at collision (1), is unchanged in the vertical plane (2), or is pressed downward (3). In the first case the driver is thrown forward and downward in relation to the vehicle, in the second case he moves forward horizontally in relation to the vehicle, and in the third case he is thrown forward and upward. From this follow the differences to be expected.

If the driver is thrown forward and downward, the head may strike the steering wheel, the chin frequently striking the steering wheel hub. This can result in a traction in the cranio-cervical junction, since the trunk is thrown under the instrument panel, especially if the latter is placed high, whereas the chin remains caught on the steering wheel. Complete or incomplete ring fractures of the base of the skull or hangman's fractures of the axis can result. (This also occurs when the steering assembly is pushed into the vehicle and strikes the driver's chin.)

If the driver is thrown forward horizontally in the vehicle, the anterior chest wall strikes the steering wheel. This situation is particularly dangerous when, as is often the case in older vehicles, the steering wheel spokes break off or bend. If this happens the trauma is transmitted to a relatively small portion of the anterior chest wall which is deeply impressed into the interior of the thorax, causing severe intrathoracic and intra-abdominal injuries. Conditions are rather different today, however, since many modern steering wheels do not usually deform in such a way as to constitute a danger to the driver on impact, and in certain vehicle models they are so constructed as to absorb energy as they come to lie against the whole of the anterior chest wall.

Cadaver experiments have shown that in a collision at 50 km/h, when the anterior chest wall strikes the steering wheel it can be subjected for about [illegible] msec to a force of approximately 2000 kp (Coermann et al 1972) If the impact is against a small part of the steering wheel in the region of the lower half of the anterior chest wall then the so called shoveling effect (Voigt 1968) can cause not only ruptures of the liver and sometimes heart damage but also an aortic rupture at the classical site (i e just below the insertion of the lig arteriosum Botalli or just below the exit of the a subclavia sin ), in such cases, the lower part of the anterior chest wall is impressed from in front and below, causing the intra aortic soft parts to be "shoveled" cranially into the arcus aortae This causes a cranially directed displacement of the arcus aortae, its deflection and thus an overstretching in the area of the insertion of the lig arteriosum Botalli Furthermore, the compression of the intrathoracic organs leads to a raised intraaortic pressure which, together with the deformation of the aorta seems to lead to rupture Aortic ruptures have been caused experimentally in cadavers by a blow to the lower part of the anterior chest wall and it has been shown that the aorta tolerates an intra aortic pressure of about 1200 mmHg under dynamic conditions (Voigt et al 1973) If the pleura mediastinale is not injured in conjunction with the aortic rupture, the patient can survive the aortic rupture long enough to make surgery possible If no such steps are taken the wall of the resultant pseudoaneurysm of the aorta may later rupture into the left pleura and occasionally even into the oesophagus

If the front part of the vehicle is pressed downward in the collision, the driver's forehead may strike the windshield or, even more dangerous, the upper frame of the windshield If the forehead strikes the upper frame of the windshield, ring fractures of the base of the skull (traction) or fractures of the dens axis may occur, caused by backward dislocation of the dens (shearing effect) If, in this situation, an angular acceleration of the head occurs, i e rotation about a transverse axis, there is a danger of rupture of sagittal bridging veins (vv cerebri sup ) or of gliding contusions in the brain The rupture of all or numerous bridging veins indicates the simultaneous presence of microscopically detectable bleedings in the brain stem (Voigt & Saldeen 1968) Such patients immediately become deeply unconscious, dying later, or else they die at once There is no evidence of any subdural bleeding worth mentioning The rupture of only one or some few sagittal bridging veins leads to subdural hematoma Gliding contusions are characterized by parasagittal subcortical and subarachnoidal bleedings in the region of the caudal part of the gyrus frontalis sup or sometimes of the central gyri and later lead to deep-seated local necroses (Voigt & Lowenhielm 1973) Experimental investigation [illegible] show [illegible]

with [illegible]

hieln [illegible] collisions the driver may sustain a posterior

fracture-luxation of the acetabulum or fractures of the femur and patella as a result of the impact on the instrument panel or—what is even more dangerous—against the fire wall (dashboard injury) (Breton & Blondeau 1927)

*Front-seat passenger* Unrestrained front-seat passengers generally strike their heads against the windshield or—when the front of the vehicle is pressed downwards on collision—against its upper frame Ring fractures of the base of the skull, ruptures of bridging veins, and gliding contusions of the brain may result, and also fractures of the dens axis caused by backward dislocation of the dens Fractures of the dens axis may also occur, however, when the front of the vehicle is raised on collision and the upper portion of the anterior chest wall or the lower portion of the neck strikes the instrument panel, the head continuing forward The dens fracture in this case is the result of a shearing effect due to forward dislocation of the dens (Sköld) Occasionally the upper jaw strikes the instrument panel, sometimes giving rise to Le Fort fractures As far as the windshield is concerned it has been shown that the impact of the head against toughened glass is more dangerous than that against laminated glass (Mackay et al 1970)

The impact of the chest against the instrument panel may lead to a sagittal compression of the thorax, possibly resulting in a dislocation of the heart caudally to the left and consequent overstretching and rupture of the aorta ascendens or to a rupture of the truncus brachiocephalicus Aortic ruptures at the classical site are also possible, particularly when the lower part of the trunk is thrown under the instrument panel and the trauma directed toward the lower region of the anterior chest wall (Voigt 1968)

Just as is the case with drivers, the impact of the knee joint against the instrument panel or fire wall leads to so-called dashboard injuries If the passenger was sitting with his legs crossed when the accident occurred (or if it was an oblique head-on collision), the outside of the knee joint may strike the instrument panel, causing the thigh to be pressed diagonally against the anterior pelvic wall, with resultant impression fractures, producing a butterfly-shaped fragment of the anterior pelvic wall or vertical fractures of the hip bone behind the acetabulum, generally accompanied by fractures of the femur (dashboard injury Type 2) (Voigt 1965)

Driver and passenger can be protected in cases of head on collision by restraint systems The choice today is between belts and the air bag Three-point belts are

superior to the other types of belt With diagonal belts there is always the danger of sliding under particularly when the occupant is thrown out of the vehicle or under the instrument panel The chin may remain caught by the belt which can even lead to decapitation (Saldeen 1967 Voigt 1968) The use of lap belts alone offers no protection against the impact of the head against the instrument panel possibly with hangman s fracture of the cervical spine as a result (Schneider et al. 1965) When the three point belts are used neck injuries or ruptures of the para sagittal *bridging veins occasioned by angular acceleration of the* head are not likely as experience has shown in Sweden (Skold) Stretchability of the belts is a prerequisite for their affording proper protection Cadaver experiments by Schmidt & Kallieris (1974) have shown that belts which stretch only up to 6 or 8 per cent can cause severe thoracic injuries The belts normally in use in Sweden stretch about 25–35 per cent and experiments have shown that under static loads up to 65 per cent stretching can be obtained This means that the driver protected by a belt can move a very long way forward in a head on collision and strike the steering wheel This is especially likely when unrestrained back seat passengers are thrown against the front seat occupants thus causing the belts to be doubly strained In many vehicles increased attention should be given to this fact when new models of steering are designed Air bags are considerably more expensive than belts and offer no protection when the vehicle suffers from further collision effects (roll over) after the primary impact and also one must expect the head to be retroflected after the impact with the air bag Ruptures of the parasagittal bridging veins and injuries to the cervical column are to be expected as cadaver experiments have shown

The restraint systems offer protection, in oblique head on collisions, against the head striking the side pillars of the windshield an impact which quite often leads to extremely serious skull injuries

*Side collisions*

If in a side collision the region of the temple is struck, this can result in a ring fracture of the base of the skull due to torsion effect (Voigt & Skold 1974) In other cases the blow from the side can cause impression fractures and/or transverse fractures of the base of the skull and intracranial injuries

The trunk is in particular danger Here it must be noted that in side collisions the trauma is mainly directed at unrestrained car occupants from ahead and from the side towards the thorax and only seldom directly from the side since as a result of the original movement (direction of travel) the occupant is thrown forwards and to the side and strikes the inside of the door Apart from rib fractures, ruptures of the spleen and liver as well as lung injuries are frequent Especially when the trauma comes from the left, aortic ruptures at the classical site may occur Characteristic here are column fractures of the first

two ribs (Voigt 1968). The surrounding injuries to the soft parts suggest that the anterior chest wall has been displaced to the right, probably causing the arcus aortae to be pulled to the right as well.

Displacement of the heart may lead to ruptures of the pericardium and heart injuries, primarily in the region of the atrial septum.

The trauma affecting the occupants sitting on the collision side and directed towards the pelvic region occasionally leads to Duverney's fracture, and more often to fractures of the pelvic ring. The most serious form is the central fracture-luxation of the acetabulum. The ramus superior of the pubis is the weakest region of the pelvis. A trauma from the side can lead to a flattening-out of the hip bone and result in a fracture either just in front of the eminentia ileopectinea or closer to the symphysis. Pelvic ring fractures usually are multiple due to the anatomical form of the pelvis. As the pelvic ring proper is pentagon-shaped on the outside, the flattening out of one hip bone reduces the angle between the sacrum and the os ileum, or alternatively the angle of the symphysis. The result is thus vertical fractures in the region of the apexes of the angles. This is the explanation of the well-known vertical fractures of the massa lat. of the sacrum and also of the parasymphysial fractures. The symphysis itself is often protected from injury by the strong presymphysial aponeurosis (Voigt 1965).

*Rear-end collision*

In rear-end collisions, the greatest danger for the front seat occupants is that the backrests of these seats may be bent backwards. If this happens, the occupant is thrown backwards and the head strikes structures at the back of the vehicle, or may even strike the other vehicle through the rear window. The results may be impression fractures of the skull and injuries to the cervical vertebrae. If the backrest is not bent backwards, whiplash injuries of the neck may occur, particularly if the upper edge of the backrest is at neck level. Such injuries, however, are seldom fatal. Headrests offer protection against this type of injury, as long as they reach up to eye level and cannot be bent backwards by the impact of the head. Three-point belts offer no protection in rear-end collisions.

*Injuries to unprotected road users*

When pedestrians, cyclists and moped riders are struck by a motor vehicle and thus subjected to a high rate of acceleration, deformations

result at the point where the vehicle hits the body, further deformations are caused by violent movements of the parts of the body not submitted to the direct trauma, and finally deformations are caused by the secondary impact with the road surface. This leads to multiple injuries where it is often difficult or impossible to say in which phase of the complicated process the different injuries arose.

First of all, at the moment of impact of the motor vehicle there occur fractures of the lower legs, which are to be regarded as flexion fractures pure and simple. When the thigh or buttocks strike the radiator surround of a passenger car, this can cause very considerable decollements, to which little attention has been paid clinically up to now. What occurs is a laceration of the subcutaneous fatty tissue, resulting in large hollows with blood and lacerated subcutaneous tissue. The danger of a fat embolism as a result of such injuries is obvious. Injections inadvertently given in such décollements can lead to infection. After absorption of the blood, the decollements result in seromas.

If the back side of one of the legs of a pedestrian is not caught by the front part of the vehicle it may be thrown violently backwards, with a pelvic luxation as the result. The reason for this is that the thigh that is thrown back draws the ipsilateral hip bone with it, which results in a rotation of the hip bone about a transverse axis through the sacrum (Voigt 1965). If the symphysis is not torn apart by this, then the surround of the contralateral foramen obturatorium may be deformed and fractured. The deformation of the vertebral column and thorax brought about by the violent movement of the trunk may lead to multiple fractures. According to the speed of impact and the design of the front part of the vehicle, the head of the pedestrian or cyclist may strike either the motor hood, the windshield or its side pillars, or the front of the vehicle roof. Impression fractures of the skull are possible, as are fractures of the cervical vertebral column.

Concerning the origin of injuries to pedestrians struck by vehicles, investigations are currently being carried out in various research centres. So far little is known about how the design of the front parts of vehicles influences the injury pattern of pedestrians and cyclists hit by them.

As far as the injuries resulting from high-speed motor cycle accidents are concerned, it can only be emphasized that the injuries of riders and passengers who have been thrown off are severe and multiple. The only protection that can be offered is the abolition of the motor cycle.

SUMMARY

A short survey is given of the main patterns of injuries sustained in traffic accidents The following injuries are accounted for ruptures of the parasagittal bridging veins and gliding contusions of the brain axis fractures and aortic and pelvic injuries

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## SUMMARY

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daily living depend on our ability to move, in the case of sports activities, rapid coordinated and strong movements are necessary These movements in turn depend on our capabilities for producing muscle forces that can move the bones making up the joints

The muscular, gravitational and ligamentous forces in our body have both internal and external effects The external effect of a force on a body is to cause an acceleration of the body In the case of a tennis player, muscle forces are used to impart an acceleration to the racket The racket then imparts an acceleration to the ball, producing the velocity necessary to carry it over the net There is also an internal effect which causes a state of strain in the body, that is, it effects a change of shape in the body As the racket strikes the ball, the ball is compressed Whether or not this state of strain will cause permanent damage to the structure depends upon its particular material properties

In applying biomechanical analysis to sports injuries, one must constantly keep in mind this inter-relationship between force and motion The science of biomechanics provides exact ways of measuring the forces and motion and allows one to determine the effects of forces on the tissues It also allows one to understand the injury mechanism and possible injury preventative measures

*Mechanical properties of locomotor tissues*

The ligamentous, tendinous, muscular, cartilaginous and bony tissues that make up the locomotor apparatus demonstrate complex mechanical properties including time-dependent viscoelastic behaviour, anisotropy and ageing effects The basic data to be determined inculde the yield and ultimate stress and strain, energy to failure, and moduli of rigidity and elasticity at realistic strain and load rates With these data predictive mechanical and mathematical models of structural behaviour may be made

*Ligament*

Noyes et al (1974) noted that the anterior cruciate ligament is strain rate sensitive in primates Tension failure occurred at a higher load, elongation and energy absorption at a fast rate of deformation than at a slow rate The site of failure was also influenced by the loading rate At the slow deformation rate, the bony insertion of the ligament was the weakest component and a tibial spine avulsion

Acta orthop scand 46, 484–497, 1975

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# RECENT ADVANCES IN THE BIOMECHANICS OF SPORT INJURIES

VICTOR H FRANKEL & YI-SHIONG HANG*

The causes of sports injuries are numerous and include such factors in the physical and psychological make-up of the athlete, his environment, training, playing field, coaching and the rules of the particular sport in which he is participating Although our knowledge of the mechanism of sports injuries has been attained in the past through the use of observational and epidemiological data utilizing the deductive technique, we are now able to gain much information from inductive studies which depend upon scientific measurement and experimentation Methodology has been discussed by *Groh & Baumann* (1971)

The tools of Biomechanics are useful in studying many of the factors which are important to sports injuries An injury is the result of tissue trauma Questions which must be answered are

What are the stress, strain and energy levels that cannot be exceeded if injury is to be prevented?
What are the structural loads that result in tissue tolerance being exceeded?
What is the effect of motion on structural loading?
How may the effects of forces on the tissues be modified through training, technique and protective equipment?

In this paper we have summarized recent experimental knowledge which has clinical importance in the prevention and treatment of sports injuries and which is solidly based on Biomechanics data

Biomechanics is a study of force and motion and the inter-relationships between them, including control mechanisms Our activities of

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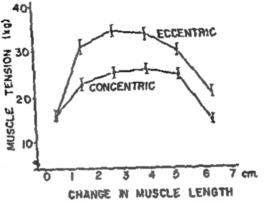



*Figure 2 The length tension relationship for the elbow flexor muscles in eccentric and concentric work Velocity 0 8 cm/sec (After Komi P V (1973) Medicine and Sport Biomechanics III 224 229 )*

than is commonly realized may be required before the functional capacity of a ligament returns to normal

Laros & Tipton (1971) studied the force required to rupture or avulse the medial collateral ligament in dogs after various levels of activity In terms of body weight there was a difference between caged animals which required a force of 2 8 times body weight and exercised animals which required a force of 3 5 times body weight to separate the ligament They noted in histological preparations that periosteal resorption about the ligamentous insertion was found in both caged and immobilized animals Increased mechanical strength of ligament after conditioning is of considerable interest in terms of athletic injury

*Muscle and tendon*

Studies which are important in an understanding of the muscle and tendon lesions have been reported by Komi (1973), who used a dynamometer to measure the force velocity relationship of the forearm extensor and flexor groups The maximum tension of the forearm flexors was always greater in eccentric than in concentric contractions (Figure 2) This phenomenon of muscle behaviour is influenced by the velocity of contraction With increasing velocity the maximum eccentric tension at each muscle length increases and the concentric force decreases This type of information is important in understanding such diverse injuries as high jumper s knee rupture of the Achilles tendon and avulsion fractures

fracture resulted At the fast deformation rate, which more closely approximated physiological loading conditions, there was an increased frequency of ligamentous failure This suggests that with the increase in deformation rates, the strength of the bone increased faster than did the strength of the ligament The authors also noted that in their experiments the ligaments elongated approximately 57 per cent prior to failure They also noted, however, that the visual determination of continuity of a ligament often gave an inadequate determination of the extent of ligamentous disruption A ligament which appears clinically intact may have undergone extensive internal failure or have internal damage to its blood vessels

In a further series of experiments, Noyes et al (1974) studied the effect of immobilization on the strength of the anterior cruciate ligament Primate knees were immobilized for 8 weeks, following which the strength of the anterior cruciate bone-ligament-bone preparation was determined There was a significant decrease in maximum failure load and energy absorption to failure and an increase in ligament extensibility (Figure 1)

After 20 weeks of resumed activity, there was only partial recovery in ligament strength A voluntary isotonic exercise program during limb immobilization did not prevent disuse-induced changes in the ligament failure properties Applications of these results suggest that following relative or complete immobilization, a longer period of time

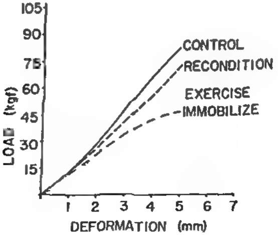



*Figure 1 Load deformation curves of ligament behaviour in primates A significant decrease in stiffness (slope of the load deformation curve) is seen in the exercised and immobilized groups Partial recovery occurred at 20 weeks (After Noyes et al (1974) Biomechanics of ligament failure* J Bone Jt Surg 56 A 1406–1418 *)*

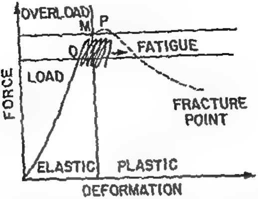



*Figure 3 Cyclical loading and unloading in the fatigue one a slow bone deformation is observed progressing to the plastic phase (After Chamay A (1970) Mechanical and morphological aspects of experimental overload and fatigue in bone J Biomech 3 263 270 )*

stress for a visually normal joint was 40 kg/cm² The exact relationship of load attenuating capacity and energy absorption ability of articular cartilage in response to athletic activities is still not clear because the magnitude and distribution of the forces applied to cartilage are unknown

*Bone*

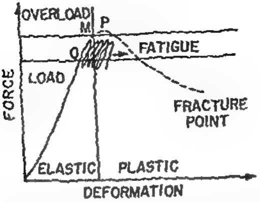
Burstein et al (1973) have demonstrated that bone is not brittle but on the contrary, may undergo large plastic deformations This plastic yielding in tension acts to enhance the strength of the whole bone due to the "plastic hinge" effect Chamay (1970) has noted the presence of shear failure in bone loaded in compression (Figure 3) This fact is of the utmost importance in considering bone remodelling and the presence of fatigue fractures Frankel (1972) has presented a theory of fatigue fractures in the athlete which is based on the fact that muscle fatigue leads to abnormal bone loading conditions which induce altered states of stress and strain in the bones This leads either to a tension crack or to shear failure in compression A fatigue failure in an athlete occurs because bone fails as it is loaded in the plastic region at a rate exceeding the normal rate of the bone repair A knowledge of the mechanical properties of the bone tissue and its response to load is necessary if one wishes to understand the mechanism and prevention of fatigue failure

Viidik (1969) reported experiments demonstrating the effects of training on an Achilles tendon preparation Rabbits were trained in a running machine and the mechanical properties of the tendon were studied The slope of the linear portion of the load-deformation curve became steeper with training, indicating an increasing stiffness in the tendon with activity The elongation at failure, the failure energy and the maximum load did not change The failure site was the insertion of the Achilles tendon at the calcaneus

Barfred (1973) has summarized past knowledge and added new information in his monograph He noted that the rupture limit for muscle has been poorly understood with respect to tensile strength and to elongation and that these failure limits must depend on the state of contraction of the muscle The maximum isometric muscle force for man was stated by Buchthal & Schmalbruch (1970) to be 5 6 kp/cm Barfred's experiments were performed by quick elongation of stim ulated muscle tendon units utilizing a rat limb preparation Ruptures were noted at varying sites in the muscle-tendon preparation The frequency of tendon rupture was highest after a period of inactivity The risk of tendon rupture increased when the muscle was exhausted The elongation at rupture always exceeded the muscle-tendon length The tensile strength and elongation at rupture limit were least in the inactivity group The muscle which could develop the greatest force also had a greater separation force than the tendon, especially if it was contracted during the rupture experiment Elongation of the unit at failure was greater when the experiment was performed with an uncontracted muscle

*Cartilage*

Freeman (1973) has summarized current knowledge of the mechani cal properties of joint cartilage, restating the two-stage compressive deformation phenomenon noted by Hirsch (1944) An instantaneous deformation occurs as load is applied Due to creep, continuous de formation occurs as the load is allowed to remain Most likely this phenomenon is related to the flow of water through the matrix An important finding was that the mechanical properties of cartilage differ in different anatomical locations These results reflect that the strength and stiffness of cartilage are strongly related to the extent to which the collagen fibres are oriented parallel to the direction of tension The maximum failure stress recorded for cartilage was 348 kg/cm² for a parallelly oriented surface layer and the minimum failure

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Nilsson & Westlin (1971) using a photon-absorption method studied bone density in 64 male athletes and compared this result to 39 healthy age-matched non-athletes The athletes had significantly higher bone density in the distal end of the femur than did the non athletes Significant evidence was produced that sports activity enhanced bone density

*Mechanical properties of structures*

This includes the behaviour under load of structures such as the long bones, the spine and individual joints Data acquisition includes experimentation with clinical load directions and load rates Data to be recorded include load-deflection relationships, energy absorption characteristics of the structures and failure modes

*Spine*

Markolf (1972) studied fresh human segments in order to measure the deformation in response to various types of movements He noted non-linearity of the moment deformation curves with increasing stiffness as deformation increased Torsional stiffness showed a marked change at the T-11/T-12 segment and he hypothesized that this discontinuity represented a site of structural weakness for torsional stress to the spinal column He noted that the intervertebral disc was 1-1/2 to 3 times stiffer in compression than in tension

Farfan et al (1970) have made the important observation that torsional loading was responsible for intra-discal failure and that *in vivo* disc degeneration was due to imposed torsional strains rather than to compressive loads Nachemson & Elfstrom (1970) have measured intra vital pressures in the lumbar disc during common movements and exercises

*Skull*

Radiotelemetry was used by Reid et al (1974) to study the acceleration peaks resulting from impacts to the head from football contact The peak ranged from 40 to 530 G's, while the duration was from 20 to 420 milliseconds He noted that the neuromuscular response to the athlete was such that the head was positioned to cause the blow to glance off and allow the smooth hard exterior of the shell of the helmet to deflect the blow

Ommaya et al (1973) studied cerebral concussion in the chimpanzee

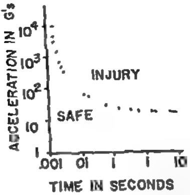


*Figure 4 Relation between acceleration and time required to produce human injury Note that high acceleration can be endured for only short lengths of time without trauma while lower acceleration can safely last much longer (Modified from Lissner et al (1960) Acceleration and intracranial pressure changes* Surg Gynec Obstet 111 329–338 )

following angular acceleration of the head and neck They noted that when the head experienced an angular velocity exceeding 70 to 100 rad/sec, irrespective of how far the head was allowed to rotate, concussion was produced Shear stresses and strains produced by the inertial loading produced the brain lesions There is a strong relationship between peak acceleration, duration of acceleration and injury as noted in Figure 4 (Lissner 1960) These studies demonstrate that cerebral damage can occur without a direct blow being delivered to the skull

Schmid et al (1968) studied the efficiency of headgear in prevention of head injury during boxing and ascertained that the use of headgear reduces the acceleration by about 15–25 per cent, that is, acceleration of 175 m/sec² with headgear and 250 m/sec² without headgear After the introduction of headgear, only 0 8 per cent of contests ended in a knockout, while formerly it used to be 3–4 per cent Peak force with different sizes of gloves was further investigated by Unterharnscheidt (1972) Use of 8 0z gloves could result in head acceleration of more than 100 G s Peak force obtained with 6–oz gloves was 2 7 times greater than that obtained with 16–oz gloves

### Epiphyseal plate

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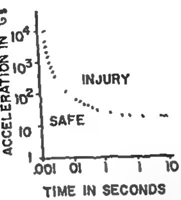


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visco-elastic properties Histological sections through the bones tested to failure demonstrated that the failure plane took a varied path through the different zones of epiphyseal plate When the structure was loaded with a load which was 50 per cent of that which would cause failure, internal cracks within the epiphyseal plate are seen in the areas exposed to the highest shear stress If the load was then released, the shear cracks remained and their presence weakened the plate for further application of a transverse load If the force was allowed to increase, the secondary crack then became the propagating crack and passed through the plate to cause cartilage failure Should human epiphyseal plate also develop shear cracks with subcritical loading, these experimental findings would help to explain the observed clinical symptomatology related to growth plate injury without radiological confirmation of disruption

*Kinematics and kinetics*

This scientific study of motion (kinematics) such as kicking and throwing is performed to develop an understanding of the linear and angular displacements, velocities and accelerations that the structures undergo during sports activities

From the acceleration data the loads on the structures can be calculated using the Newtonian laws

Force = Mass × Acceleration
Torque = Mass moment of inertia × Acceleration

Since energy is transformed constantly during sports activity, an understanding of energy transfers from the potential to the kinetic to the strain form is of value When strain energy is allowed to reach certain levels, failure of the structure occurs depending upon the particular mechanical behaviour of the structure and its component tissues

*Kicking*

Frankel & Burstein (1970) have analyzed the forces in punting a football and noted that for a maximal effort in punting, the force developed by the quadriceps tendon was approximately 3 times body weight Youm & Huang (1973) have developed a computer program for studying simulated kicking

*Throwing*

Using motion picture analysis, Tullos & King (1973) studied the mechanism of pitching in baseball. Their data support the fact that the highest acceleration force occurs at the beginning of throwing. The authors note that at the beginning of the acceleration phase, there is a valgus stress on the lateral side of the joint which may be responsible for the capitellar injuries noted in the elbow.

*Jumping*

Ramey (1970) utilized a force plate to determine the force-time relationships during the running long jump. His findings show that the maximal vertical force exerted at take-off is not the sole important parameter but that a combination of force, impulse and the mass of the athlete were primary factors in the ability to perform the long jump. He also demonstrated that the horizontal forces that exist at take-off act to decrease the horizontal take off velocity.

Gombac (1971) studied the mechanics of take off in the high jump. He noted that the vertical force on the ground exceeded 350 kg. He divided the take-off into three phases.

*Leg placing* – – It was during this phase that force against the ground was at the maximum.

*Amortization* – A firm base of support of the whole foot was established. During this period of time, knee flexion took place so that the observed ground reaction force decreased to 100–150 kg.

The third phase was *active take off*. There was an increase in vertical force. Amortization phase may be of great importance in the production of "high jumper's knee" in that the knee flexes under the control of very strong quadriceps forces, producing peak forces on the patellar tendon and its attachments.

*The knee joint*

The knee joint is the area on which the most intensive studies have been performed. Much good data now exist on the loads of the joint, the strength of the structures and tissues, and the mechanism of injury.

Great emphasis has been given to studies of the knee joint due to the many injuries encountered. The forces acting on the knee joint have been analyzed by Lindahl et al. (1969). They noted that the mean force exerted by the quadriceps was 520 kgf, which was equivalent to a force of 2.9 kgf/cm² of muscle cross section. The muscle force exerted

by the quadriceps in extension of the knee was determined in healthy males and found to vary with the position of the knee The maximum moment of 2300 kgf-cm was recorded at 60–75 degrees of flexion

Reilly & Martens (1972) studied the quadriceps muscle force and the patello-femoral joint force for various activities The patello femoral reaction force was at a maximum at 30–40 degrees of flexion During deep knee bending the patello-tendon force reached a force of 7 6 times body weight For stair climbing and descending, the force attained a level of 3 3 times body weight, which is almost seven times the force reaction found during normal walking and explains why patients with patello-femoral derangements experience more pain while climbing stairs Quadriceps exercise performed by extending the knee from *90 degrees against the resistance of a boot weighing* 9 kg yielded a patello-femoral force of 1 4 times body weight, explaining why some patients complain of retropatellar pain during the exercise A straight leg raising exercise of similar weight produced a patello-femoral force of only 0 5 times body weight

Instability of the knee is an important clinical finding Experimental production of injuries resulting in instability has been performed by Kennedy & Fowler (1971) on a knee loading apparatus Different combinations of forces and varying speeds were applied to cadaver knees In the case of abduction and external rotation forces, the ligaments rupture in the following order medial capsular ligament, tibial collateral ligament and finally the anterior cruciate ligament

When the knee was placed in a position of 90 degrees of flexion, 30 degrees of external rotation could be produced without injury At between 40 and 50 degrees of external rotation the tibial collateral ligament was found to be intact in the presence of a ruptured capsular ligament With disruption of the medial capsular ligament, the usual clinical abduction tests failed to reveal gross medial laxity despite the obvious damage When further external rotation combined with abduction was applied, damage to the tibial collateral ligaments was evident, but no damage to the anterior cruciate ligament occurred until the tibial collateral ligament had ruptured

Alm et al (1974) reported experiments on the tensile strength of the anterior cruciate ligament using a dog preparation In 94 per cent of the tests ruptures occurred in the mid-part of the ligament They noted that rotation of the tibia of an intact knee in man was considerable with the knee in semiflexion The results of their study suggested that trauma causing rotation of the tibia decreases the tensile strength of

the anterior cruciate ligament and increases the risk of rupture Kennedy et al (1974) stated that tension of the anterior cruciate ligament was greatest in full extension and in 5–20 degrees of flexion The ligament was almost relaxed between 40 and 50 degrees and gradually became tauter as flexion increased to 70–90 degrees They stated that isolated tears of the anterior cruciate ligament occur as a result of internal rotation displacement of the tibia in relation to the femur

Quasi quantitative tension studies of the anterior and posterior cruciate ligaments of human cadaveric knee during various degrees of flexion were performed by Detenbeck (1974) He found that tension of the anterior cruciate ligament decreases progressively with knee flexion, and that of the posterior cruciate ligament decreases with initial knee flexion, but beyond 30 degrees, it increases progressively Maximum combined cruciate tension is least between 30 and 60 degrees of knee flexion The posterior cruciate ligament appears to guide the screw-home mechanism or internal rotation of the femur during terminal extension of the knee while the anterior cruciate ligament stabilizes the lateral femoral condyle on the tibia

Warren et al (1974) studied the function of the ligaments along the medial side of the knee They concluded that the long fibres of the superficial medial collateral ligament are the primary stabilizer against valgus and rotatory loading The long fibre as a *functional unit* has a complex pattern in which the anterior most fibres tighten as the knee flexes from the position of extension, and simultaneously the fibres just posterior to them slacken The long fibres arise from a critical point on the medial femoral condyle relative to the instant centres of rotation such that the anterior border is kept under tension from full extension to 90 degrees of flexion Cutting the deep ligament and the posterior capsule produces almost no change in joint opening under valgus load if the long fibres are intact Great valgus instability resulted from dividing the long fibres

When a specific sports injury is encountered, a logical schema must be developed to analyse it fully One must not forget the elements of control which are reflected in skill, trainability and performance and which may be strongly under the control of emotional forces and may decay with age

The various protective devices may also be studied in a manner similar to the locomotor tissues and structures Devices which are used to enhance ability such as shoe cleats and ski boots must also be analysed for their effect on structural loading and kinematics Newer

playing surfaces developed during the past few years to overcome the problems of maintaining turf also change the quality and quantity of the ground and environmental reactive forces

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Acta orthop scand 46, 498–506, 1975

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# SPONDYLOLYSIS AND SPONDYLOLYSTHESIS

Giorgio Monticelli & Elio Ascani

Despite the numerous clinical and experimental contributions about spondylolysthesis, a number of problems still remain A periodic review of the subject is therefore justified in order to clarify the progress however modest, that has been achieved over the years, and to consolidate the knowledge about the complex subject of orthopaedic pathology

Our examination of recent literature, as well as the experience gained from surgeons who have been devoting themselves to the study and treatment of this skeletal disease for a long time—(the initial studies of one of us go back as far as 1956)—have led us to concentrate here on certain more significant aspects of the disease which have now become clearer

We shall therefore discuss a) the importance of stress in the etiology of lysis, b) the mechanism of slipping, c) therapeutic indications and methods applied

Among the various theories put forward to account for the origin of the lysis, the one we consider the most probable is that of a condition of chronic overweight, which leads to the type of injury known as a ' duration fracture"

In support of such a theory, there do in fact exist both theoretical considerations, demonstrable by photoelastography and by calculating the distribution of the weighting forces, as well as clinical observations of cases demonstrating this theory which recently have been reviewed by various authors

Extremely significant are the cases in which it has been possible to radiographically document the appearance of lysis in previously healthy people In recent years, more than 10 cases have occurred in which the lysis appeared after a lumbar sacral fusion at the level of the vertebra above the fusion

Equally important are those cases in which the lysis appeared following a serious dorsal kyphosis followed by hyperlordosis

We have investigated athletes who practice sport activities with continuous and heavy loads applied on the lumbar spine postured in hyperlordosis viz diving, weight-lifting and wrestling, and in various cases, we have been able to demonstrate the appearance of either a mono- or a bilateral lysis

These observations, which until a few years ago had passed almost unnoticed, have convinced us of the importance of stress (meant both in its static sense and also more probably in the dynamic sense) in the origin of the lysis Whether the giving way should occur on a base altered by a trophic defect (as Holits and Jaeger maintain) or on a displasic base (as Brocher maintains) has been impossible to determine

The stressing action of the weight, and certain physical activities, causing lysis, may help explain the mechanism of slipping

According to accepted theories, slipping of the olisthetic vertebra occurs during childhood and adolescence and then stops at adulthood

Even here the accepted opinions must be revised in view of the fair number of recent observations of slipping worsening in adulthood

Undoubtedly, worsening of the olisthesis after the age of 20 is rare, but it is certainly not as exceptional as Taillard maintained until a few years ago

It is more difficult to explain why slipping should stop once it has been started by the yielding of the elastic properties of the disc capsule ligament system

From the biomechanical studies we have carried out we maintain that slipping may take place according to two mechanisms

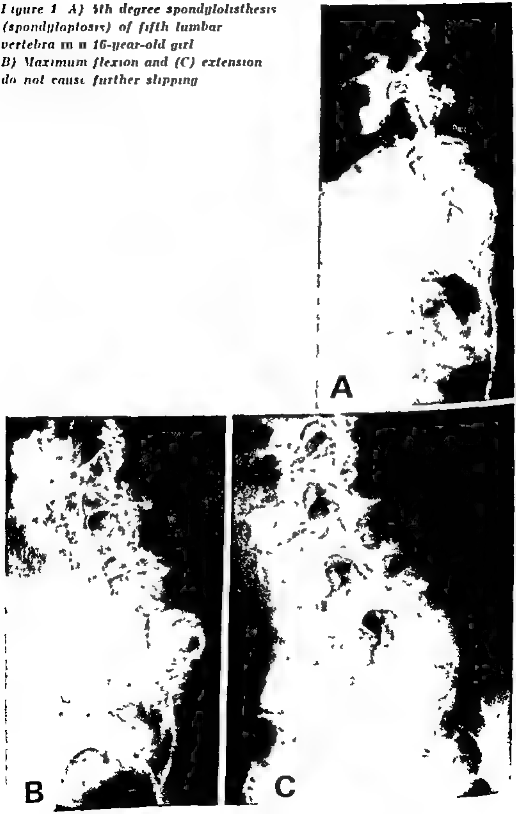
a) By overcoming the hysteresis of the posterior ligaments and of the disc as a result of a repeated or sufficiently powerful traumatic action or by a process of degeneration of the disc, with gradual loss of its elastic properties which oppose slipping

The first mechanism might be used to explain the olisthesis which we have observed in adult athletes whose discs show no radiographic signs of degeneration

In both cases, slipping would stop on reaching a state of compensation which is elastic in the first case and absolutely plastic in the second

The maintenance of an elastic state explains, in our opinion, the resistance to the stressing action which we have noticed in athletes who continue to pursue a fair amount of sports activity without suffering any further worsening of the olisthesis

Figure 1 A) 5th degree spondylolisthesis (spondyloptosis) of fifth lumbar vertebra in a 16-year-old girl
B) Maximum flexion and (C) extension do not cause further slipping



That the olisthesis might worsen in adulthood should be considered in the choice of treatment as a possible, even rare, occurrence, in the presence of certain conditions Consequently, the type of treatment must be conditioned not only by the symptomatology and the age of the patient, but also by other considerations such as the radiographic appearance of the discs in functional tests the value of the tangential pushing force which acts on the olisthesic vertebra, the value of the lumbar index the inclination angle of the sacrum, the condition of the abdominal muscles, the patient's work and the sports he practices, and for women, the likelihood of future pregnancies

Apart from the kinesiological and orthopaedic treatment which must always be attempted in the presence of a symptomatic spondylolisthesis, we wish to discuss in detail the different types of surgical treatment

The surgical treatment of spondylolisthesis must pursue a triple aim

1) Amelioration of the painful symptoms
2) Reconstruction of the functional alignment of the spine by reduction of slipping
3) Complete and definite stabilization

It is not always possible by surgery to fulfill all three of these aims and the choice of the primary aim to be fulfilled by one or the other type of operation is entrusted to the personal experience of the surgeon

Three different types of operation are available to relieve the most common symptoms of spondylolisthesis lumbar sciatica neurological troubles and progressive slipping of the vertebra

1) Posterior element excision
2) Excision and fusion
3) Reduction and fusion

First of all the choice of treatment is determined by the age of the patient and on these grounds we distinguish between three groups

1) Young people up to the age of 20
2) Young adults between 20 and 35 years of age
3) Adults over 35 years of age

These three groups have been classified on the basis of the likelihood that the spondylolisthesic vertebra will slip and of the physical activities carried out in each age group

In the first group, where the possibility of a worsening is the greatest, surgery aims at stabilization

Operations involving posterior element excision are to be completely avoided because of the risk of worsening

Operations involving a wide excision associated with fusion are also not recommended, especially in patients under the age of 15, both for the above reason and because of the risk that the laminectomy might induce kyphosis in the involved part of the spine

We consider that, in this group of patients, the operation to be chosen is determined by the necessity for reduction of slipping, followed by stabilization, which to be valid must come about through a double fusion, intersomatic by an anterior approach and sacro-transversal by a posterior one

The reduction of slipping resolves, in 90 per cent of the cases, all neurological symptomatology whether algic or paralytic, while if only simple lumbago exists, which is resolvable even by stabilization alone, we still believe that reduction should be performed in order to restore the balance of physiological forces

In the second group, as demonstrated, we must consider the possibility of a worsening of the spondylolisthesis, even though this is rare In this period of life the person is at the peak of his physical and sporting activities, which may cause lysis and slipping In women this is the period of prospective pregnancy, which through the weight increase, the hyperlordotic posture, and the lassitude of the ligaments may cause a worsening of the slipping

Thus, in cases of spondylolisthesis of the 3rd and 4th degree, with roots symptomatology, we consider it advisable to attempt a reduction in most cases, but the chances of ameliorating the symptoms are worse than for the younger group

A successful reduction should be followed by a stabilization operation which in women, is effected by anterior and posterior fusion In

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*Figure 2 A) The myelogram carried out with a radio opaque hydrosoluble medium (dimerix) shows a total arrest at the sub arachnoidal space corresponding to the slipped vertebra The patient is suffering from a bilateral paresis in the lower limbs B) The conservative reduction performed with the patient under total anesthesia was very successful and is maintained with the help of a plaster jacket The neurological symptoms have disappeared C) The myelogram performed with the patient braced with the plaster jacket shows the full patency of the vertebral lumen*


Figure 2.

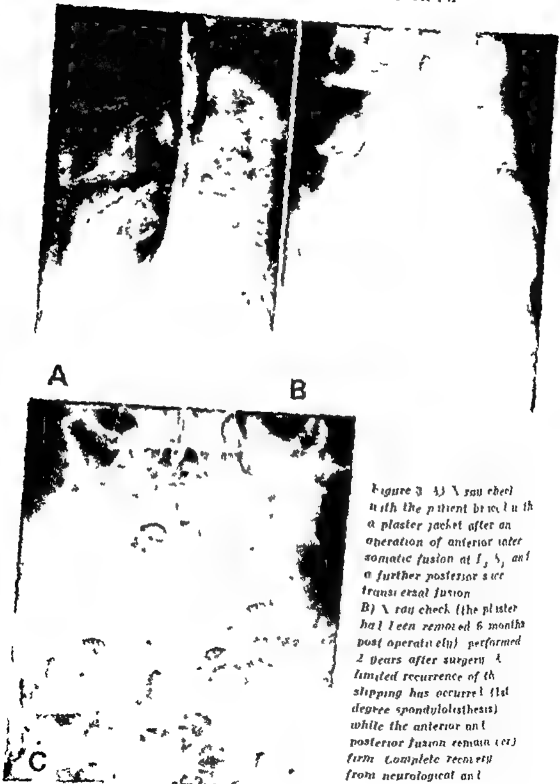


*Figure 3. A) X-ray check with the patient braced with a plaster jacket after an operation of anterior inter-somatic fusion at $L_5$-$S_1$ and a further posterior sice transversal fusion. B) X-ray check (the plaster had been removed 6 months postoperatively) performed 2 years after surgery. A limited recurrence of the slipping has occurred (1st degree spondylolisthesis) while the anterior and posterior fusion remain very firm. Complete recovery from neurological and painful symptoms.*

men, we prefer to avoid the anterior fusion because of the risk of lesions in the pre sacral plexus, and perform only a posterior fusion, which Monticelli carries out by connecting the inter-articular fusion to the sacro-transversal and then strengthening the facets between them, with a bone graft aided by screws

When reduction does not give positive results, or in cases where lengthy treatment as in fusion reduction is considered inadvisable, we prefer to perform a radiographic study to identify the cause of the pain, followed by an enlarged laminectomy with sacro transversal fusion

When it is necessary to remove the entire posterior arch, we prefer to adopt Marino-Zuco's technique by which the normal width of the vertebral lumen is restored while maintaining the position of the arch

In the few cases in which it is necessary, we perform Gill's operation in connection with intersomatic fusion by a posterior approach, or intertransversal fusion

In the third group of patients, in whom a progression in slipping is not a threat, Gill's operation is the most suitable one, because it provides the best results, restoring the patient to active life in the shortest possible time

## SUMMARY

On the basis of our own experience and the most up to-date reports, we present some of the most controversial features of spondylolysis and spondylolisthesis

In particular, the importance of stress in the etiology of the lysis has been revealed by research carried out on athletes practicing strenuous sports

It has also been shown how the slipping of the olisthesic vertebra does not necessarily cease around the age of 20, but may continue, under certain conditions even in the young adult

Finally, advice on treatment is given in relation to the various surgical techniques, emphasizing the importance of the reduction of slipping and giving directions on the use of this technique, and its limitations

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*Key words* spondylolysis spondylolisthesis slipping

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Acta orthop scand 46 507-525 1975

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# FRACTURE-DISLOCATION OF THE HIP

MARCUS J STEWART, H RELTON MCCARROLL, JR & JAMES S MULHOLLAN

In 1952 at the Combined Orthopaedic Meeting in London, we reported on a study of 194 fracture dislocations of the hip in 193 patients with a follow up analysis of 128 These patients had been seen at the Campbell Clinic over a period of 30 years Since that time, we have treated and studied an additional 222 hips in 220 patients and have been able to make a follow up study of 154 of these Our objective in reviewing these additional patients was to critically compare them with those seen in our original investigation In the majority of patients in this second study the principles for treatment and for analysis outlined in our first study have been applied Thus, we have attempted to determine whether or not our recommendations for management were valid and what changes we should make in our treatment in the future

Realizing that the literature abounds with classifications of fracture dislocations of the hip and recognizing that the one used in our original report may have shortcomings, we still elected to use it in this study because it has proven comprehensive and useful for us There are so many possibilities for subdividing a classification of fractured hips into splinter groups that to do so could lose all continuity and statistical significance

Our classifications as to positions of the dislocation are posterior, anterior obturator and central

As pertains to the extent of fracture they are Grades I, II, III, and IV

Grade I a simple dislocation without fracture or with a chip from the acetabulum so small as to be *insignificant*

Grade II a dislocation with one or more large rim fragments, but with sufficient acetabular socket *remaining* to ensure stability after reduction

Grade III an explosive or bursting fracture with disintegration of the rim and dome of the acetabulum, producing gross instability

Grade IV a dislocation with a *fracture* of the head or neck of the femur

Rowe & Lowell reported on 93 acetabular fractures in 90 patients Their classification includes linear and stellate acetabular fractures posterior acetabular fracture with small or large rim sections broken inner wall fractures with minor, moderate, or severe intrapelvic displacement, and superior and bursting fracture of the dome of the acetabulum They found, as we did, that the highest percentage of poor results are from the bursting or explosive fractures which involve the acetabular dome

We cannot agree with Larson & Sinning that in hips with "displacement of both weight-bearing dome and femoral head, a good functional hip results after minimal treatment" We believe there are indications for specific treatment of each type and grade of dislocation and that the best results are obtained when these principles are meticulously applied, adequately followed, and proper rehabilitation is accomplished

## CRITERIA FOR CLASSIFICATION OF RESULTS

We have reviewed our patients clinically and roentgenographically Again we find, as in our first reported series, that often the clinical result is superior to the final x-ray appearance of the hip However, we have combined these findings in making our final evaluation of the patient's result

An *excellent* result means that the hip returned to normal, with a full, free range of motion, the patient had no residual pain, weakness or fatigue after normal work, and the roentgenograms revealed no narrowing of the joint space and no avascular necrosis or arthritic changes

A *good* result means that the patient had no appreciable pain or limp, except after a long day of hard work and weight-bearing, and not more than a 25 % restriction of motion and this without interference of his daily activities The roentgenograms might show minimal arthritic changes, but no evidence of avascular necrosis or narrowing of the joint space

A *fair* result was characterized by mild to moderate pain, a slight limp, and restriction of motion by 25 to 50 % The patient's capacity for work, although curtailed, was still adequate for a sustaining occupation There might be moderate narrowing of the joint space, with minimal cyst formation in the head of the femur and with moderate sclerosis in the acetabulum

Patients with *poor* results had pain, limp, moderate to marked limi

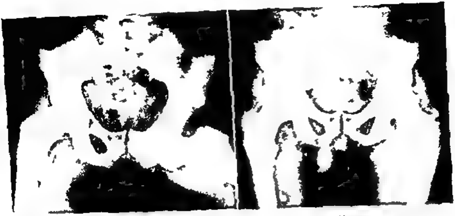

*Figure 1 A Obturator dislocation B Four year follow-up*

*Figure 2 A Posterior dislocation Grade II B Two large rim fragments but hip stable after reduction C Seventeen year follow-up*

*Figure 3 A Posterior dislocation grade III Disruption of posterior rim B After manipulative reduction and limb traction C Seventeen year follow-up Narrowing of joint and arthritis Slight pain Patient is walking with support and will soon need surgical reconstruction*

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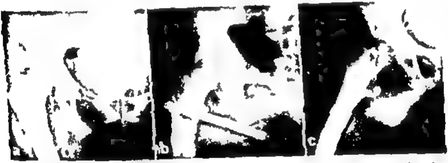

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## CLINICAL REVIEW

Our current study included 222 hips in 220 patients, two being bilateral Of these, 178 (80 %) had posterior dislocations and 36 (16 %) had central dislocations (see Table 1) The right hips were involved in 98 instances, the left in 124 This slight predominance of left hips was also present in our first study (see Table 2).

*Table 1 Type of dislocation*

| Type | Number | % |
|---|---|---|
| Post | 178 | 80 |
| Centr | 36 | 16 |
| Ant | 2 | 1 |
| Obt | 2 | 1 |
| Unl | 4 | 2 |
| | 222 | 100 |

*Table 2*

| Laterality | Number | % |
|---|---|---|
| Right | 98 | 44 |
| Left | 124 | 56 |
| | 222 | 100 |

*Table 3*

| Sex | Number | % |
|---|---|---|
| Male | 155 | 70 |
| Female | 65 | 30 |
| | 222 | 100 |

*Figure 4 Posterior dislocation, grade IV Note fracture fixed with angle nail after open reduction Poor result (necrosis of femoral head)*

*Figure 5 A Central, grade II dislocation treated by 15 pounds longitudinal and 10 pounds lateral traction Two additional views made at weekly intervals Note distraction of head from acetabulum, but this never causes difficulty*

*Figure 5 B Follow-up AP and lateral at 1 year, and AP at 3 years*

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*Figure 4 Posterior dislocation grade II Note fracture fixed with angle nail after open reduction Poor result (necrosis of femoral head)*

*Figure 5 A Central grade II dislocation treated by 15 pounds longitudinal and 10 pounds lateral traction Two additional views made at weekly intervals Note distraction of head from acetabulum but this never causes difficulty*

*Figure 5 B Follow-up AP and lateral at 1 year and AP at 3 years*

In comparing gender, there were 155 males (70 %) and 65 females (30 %). Again a striking similarity to our previous study, where there were 148 males (77 %) and 45 females (23 %) (see Table 3). Fracture dislocation of the hip is usually the result of severe and violent trauma, and males are more likely to be subjected to this type of exposure in their daily activities than are females.

## CASES FOR FINAL ANALYSIS

The final analysis included only those patients who were followed for 1 year or more. Even though the results in a few patients may change after 1 year, we agree with Rowe & Lowell that the clinical and x-ray findings after 1 year offer a reliable guide to the prognosis. Patients under 10 years of age were excluded.

Again, as in our previous study, patients with closed manipulative reduction tended to show improvement or up-grading in their results as the years passed, while the reverse is true of those who had had open operations. Granting that the hips which required open operation were probably more severely injured at the time of the original accident, no doubt operative intervention further jeopardized the blood supply and enhanced deterioration, a development which has been pointed out by many authors.

Follow-up examinations were performed by the authors in 94 patients, by other members of our clinic staff in 45 cases, and by questionaires plus x-ray films in 15.

## ETIOLOGY

The automobile remains the dominant culprit in all reported series. In our first investigation it was the cause in 70 % of the injuries, while in the current series 85 % of the injuries were attributable to the automobile Falls and falling objects caused 21 % of the injuries in the first study compared to 8 % in the second Other causes accounted for 7 % in each group The rare causes are interesting; the first study showed that motorcycle, tractor, and railroad accidents caused three each, while in the second study, motorcycles caused four, tractors one, and railroads one. Injury by horses changed from one in the first study to four in the second, by football from zero in the first study to four in the second (Table 4).

*Figure 6 Posterior grade II dislocation Reduced at 36 hours in traction for 8 weeks Three year follow up avascular necrosis and infarct in head*

*Figure 7 A Posterior grade III dislocation with inner acetabular wall instability Before reduction after reduction and after 4 weeks in traction*

*Figure 7 B Traction was discontinued at 6 weeks C Gradual redislocation D Follow up after 1 year and E After 15 years*

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the brain, spine, chest, and abdominal viscera are frequently associated with dislocation of the hip Watson-Jones warned us of the danger of the various positions in an automobile and how the knee striking the dashboard of a car with the hip flexed or legs crossed sets the stage for dislocations We believe that the left hip is more frequently injured in an automobile accident because the driver braces the left foot against the floor of the car while moving the right foot from the accelerator to the brake, the left leg is also placed in a position of wider abduction

In our current study of 220 patients, 109 (50 %) sustained associated fractures in other bones at the time of the dislocation Fifty six (25 %) had lacerations of the face and fractures of the facial bones Eleven (5 %) had fractures of the femur on the same side as the dislocated hip and in one the fracture was bilateral We believe that many of these crippling injuries can be prevented by the proper use of seat belts, and by the use of safer design principles in automobile construction

## RESULTS FOLLOWING CLOSED REDUCTION

(In The Current Study)

In 125 hips treated initially by closed manipulation, 101 were posterior dislocations, 23 were central and one was an obturator displacement The results in the 101 posterior dislocations showed 77 excellent or good results while 24 were fair or poor The 23 central dislocations showed 11 excellent or good results and 12 that were fair or poor The one with an obturator dislocation had, as expected, an excellent result Many of the fair and poor results subsequently required reconstructive operations

## RESULTS FROM EARLY SURGICAL MANAGEMENT

(In The Current Study)

Primary treatment in 29 patients involved operative reduction or operation to correct acetabular and femoral head defects Twenty four of these were posterior dislocations, and five were central The 24 hips with posterior dislocations showed 17 (70 %) excellent or good results and seven (30 %) fair or poor, while the five central dislocations showed one good and four fair or poor

Ten patients with Grade III posterior dislocations had early manipulative reduction, but their open fixation of the acetabulum was de-

*Table 4*

| Etiology | | No of hips | % |
|---|---|---|---|
| Automobile | | 190 | [illegible] |
| Falls & falling objects | | 18 | 8 |
| Others | | 14 | 7 |
| Motorcycles | 4 | | |
| Tractors | 1 | | |
| Football | 4 | | |
| Railroad car | 1 | | |
| Horse | 1 | | |
| Cows | 2 | | |
| Airplane | 1 | | |
| Total | | 222 | 100 |

*Table 5 Age at time of injury—222 patients*

| Age (years) | No of patients | % |
|---|---|---|
| 11–20 | 34 | 15 |
| 21 30 | 30 | 13 |
| 31–40 | 49 | 23 |
| 41–50 | 41 | 19 |
| 51–60 | 32 | 14 |
| 61 70 | 23 | 10 |
| 71 + | 13 | 6 |
| Total | 222 | 100 |

## AGE

The involvement acording to chronological *age* of the patients was very similar in the two groups (Table 5) Dislocations are more apt to occur during the active years of youth and middle age Before 15 years of age, the patient will more likely have a slipped capital femoral epiphysis, while after 60 years, he is more prone to fractures In this older age group it is interesting to note that three patients had associated fractures of the opposite hip

## COMPLICATIONS

Trauma severe enough to produce a fracture-dislocation of the hip will in most instances cause additional injury to the body Severe injury to

In this group there were 31 posterior Grade I's and all of these had an excellent result. Interestingly, *all 31 of these patients with Grade I* injuries were allowed full weight-bearing 2–4 weeks after injury.

*No reductions* were done between 12 and 24 hours post injury. Five hips were reduced between 24 and 48 hours after the injury and all had an unsatisfactory result. Eleven hips reduced after 48 hours all showed an unsatisfactory result. Thus 16 patients whose hips were reduced after 24 hours all had *unsatisfactory* results.

As noted in our original study and in the excellent *report* by Thompson & Epstein, a delay in reduction of more than 24 hours invariably leads to an unsatisfactory result. In our present series it is gratifying to see that in 85 out of 101 patients with posterior dislocation, the *manipulative reduction* was *accomplished* within the first 12 hours after the injury.

The results in 23 central dislocations (Table 7) showed 12 hips reduced in the first 12 hours, and of these eight had an excellent or good result and four fair or poor. The other 11 hips were reduced after 48 hours and there were 10 fair or poor results and one good. (The one good result has been followed *for only* 1 year, so this may or may not be the final answer.)

*Table 7. Results in central dislocations correlated with the time the dislocation was reduced*

| Hours | | 0–12 | | 12–24 | | 24–48 | | 48 + | | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| Grade | | E&G | F&P | E&G | F&P | E&G | F&P | E&G | F&P | |
| Central | I | 1 | | – | – | – | – | – | – | 1 |
| | II | 5 | 1 | – | – | – | – | – | 5 | 11 |
| | III | [illegible] | 3 | – | – | – | – | 1* | 4 | 10 |
| | IV | | | – | – | – | – | – | – | – |
| Total | | 8 | 4 | | | – | – | 1 | 10 | 23 |

## ANESTHESIA

General anesthesia was used in 155 patients for accomplishing *reduction*. Valium and/or Demoral sedation was used in 17 cases, spinal anesthesia in one, and nothing or unknown in 29 patients (Table 8). The use of a strong sedative such as Valium and Demoral is a recent innovation with us. Even though it is extremely important that the dislocation be reduced *as soon as possible*, it is also important that *in one's*

layed from 2–19 days, with an average delay of 6 days These showed one poor, two good and seven excellent results

In six patients with Grade I posterior dislocations the loose fragments were removed from the acetabulum Of these, two had a good result, both were reduced and operated less than 12 hours post injury In the other four patients the reduction and operation was delayed 48 hours, 23 days, 25 days, and 42 days respectively All four had a final poor result Two of these later had a successful cup arthroplasty Again, it becomes quite obvious that early and definitive treatment is imperative Epstein has emphasized the importance of early removal of any and all loose bony fragments from the acetabulum

Four patients had a prosthesis primarily, they were in the older age group, the youngest being 47 years of age, and the others 63, 66, and 76 respectively The 76-year-old had a Judet prosthesis and an unsatisfactory result, the other three had Austin Moores and good results

One patient, age 36, with a Grade IV posterior dislocation at [illegible] days post injury, had an open reduction and at the same time a fixation of an intertrochanteric fracture with an angle nail, and, as you would anticipate, a poor result

## INFLUENCE OF THE TIME OF REDUCTION ON THE FINAL RESULT

Table 6 shows the results correlated with the length of time the dislocation remained unreduced One hundred and one patients with posterior dislocations were treated initially by closed manipulation Of the 85 patients reduced within the first 12 hours after dislocation, 79 (93 %) had an excellent or good result, and six (7 %) had a fair or poor result

*Table 6 Results correlated with the time the dislocation was reduced Closed*

| Hours / Grade | | 0–12 E&G | 0–12 F&P | 12–24 E&G | 12–24 F&P | 24–48 E&G | 24–48 F&P | 48 + E&G | 48 + F&P | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| Post | I | 31 | | – | | | | | | 30 |
| | II | 32 | 1 | | | – | 5 | – | 4 | 41 |
| | III | 7 | 3 | – | | | | – | 5 | 12 |
| | IV | 9 | [illegible] | | – | | | – | [illegible] | 13 |
| Total | | 79 | 6 | | | – | 5 | – | 11 | 101 |

for as much as 2 weeks or there is x-ray evidence of bone fragments in the sciatic notch area, the nerve should be explored Nerve injury, if present, nearly always occurs in the Grades II and III posterior dislocations and is rarely seen in a Grade I or in any other type of dislocation However, we have seen sciatic nerve involvement in a Grade I central dislocation, this undoubtedly is from direct contusion of the nerve

*Table 9 Sciatic nerve injury in 220 patients*

| | |
|---|---|
| Peroneal div (only) | 18 |
| Anterior div (only) | 0 |
| Both div | 8 |
| Inadeq info | 4 |
| Total | 30 or 19% |

*Table 10 Sciatic nerve injury Results*

| | |
|---|---|
| Complete recovery | 13 |
| Incomplete recovery | 10 |
| Permanent | 2 |
| Lost to follow up | 5 |
| Total | 30 |

## SECONDARY RECONSTRUCTIVE OPERATION

In comparing the results of reconstructive operations in this current series with those in our first study, we find a great deal of conflict In the first series there were eight fusions, and three osteotomies to correct position in previously ankylosed hips, and all of these had a final good functional result In this current study there were seven fusions and only three had a good result, while four were poor (two of these were failures of fusion)

The cup arthroplasties fared only slightly better, in the original series there were ten arthroplasties with six good and four unsatisfactory results In this current series there were seven, with four good results and three unsatisfactory

No prostheses were inserted prior to 1952 In our current study five prostheses were used four had good results and one was poor Subtrochanteric osteotomy was done in only one case and this was 9 years post injury It produced a good result

haste no further damage be done to the hip, and therefore sufficient relaxation is important

*Table 8 Anesthesia necessary for reduction*

| | |
|---|---|
| Gen Anes | 155 |
| Sed (Valium or Demoral) | 17 |
| Spinal | 1 |
| Unknown | 29 |
| Total | 220 |

It is mandatory that adequate x-ray evaluation be obtained before and after reduction One must properly assess the general condition of the patient, the correct position of the dislocation and the extent of the fractures Postoperative x-ray studies should be made while the patient is still under anesthesia, the final position of the hip and that of any fragments must be accurately determined If fragments of bone are left in the weight-bearing articular surface of the joint, this will invariably produce a rapid destruction of the cartilage, deterioration of the joint, and a poor result

## SCIATIC NERVE INJURY

In our first study sciatic nerve injury occurred in 13 % of the patients and in the second study in 19 % The number of patients is too small to be of any statistical significance, but we might postulate from the increase in nerve involvement that modern trauma is becoming more violent and more severe Recovery from nerve injuries varies a great deal depending upon the site and the extent of the damage The peroneal division is more vulnerable to trauma than the anterior tibial division and its ability to recover is much inferior

Of the 154 patients followed in this study, 30 (19 %) suffered sciatic nerve injury (see Table 9) Eighteen patients had isolated peroneal division injury, but none had isolated anterior tibial branch involvement Both divisions were involved in eight patients and in four patients the description was indeterminate Recovery was complete in 13 patients, while 10 had only up to 50 % recovery, two had permanent pain and little or no return of motor function, and in five follow up information was inadequate (Table 10)

After reduction of the dislocations, if the sciatic nerve pain persists

weight bearing has a definite influence on the end result They, along with Phemister and others, also believe that this has an influence on the development of avascular necrosis, but this has not been our experience We believe that as soon as the acetabulum is stable and its fractured components healed the patient can begin full weight bearing This prolonged period of abstaining from weight bearing will have no definite influence on the end result

Traumatic dislocation in the child presents a different problem, the injury usually is much more benign than in the adult Funk, reporting on 40 traumatic dislocations of the hip in children had 14 in patients under 5 years of age He found most of these very easy to reduce by manipulation and no avascular necrosis or arthritic changes developed Four of his patients between the ages of 6 and 10 were quite difficult to reduce and three required open reduction, all of these had a poor result

In a follow up study on 51 dislocated hips, the Pennsylvania Orthopaedic Society reported similar findings, that is, children under 6 years of age had few, if any, complications They reported good results from early reduction of those reduced within the first 24 hours, 41 out of 45 had normal hips They had 18 hips in which reduction was delayed for 24 hours and results showed eight normal and ten abnormal They observed that the severity of the initial trauma had a marked *influence on* the results Reporting on those hips with less severe trauma they found that just over 14 % were abnormal, while those with more severe injury showed 60 % with poor results Like us, Funk and the Pennsylvania Group found no correlation between the period of abstaining from weight bearing after reduction and the final result

Pipkin in reviewing 55 cases of Grade IV fracture-dislocations, observed that those fractures of the femoral head that occurred below the fovea centralis showed a much better prognosis than those above this level He also noted that prompt closed reduction followed by traction or immobilization invariably gave the best results In those cases in which closed reduction could not be successfully accomplished, a small percentage of good results were obtained by open reduction with or without internal fixation of the head fragments He reported two instances of fractures of the surgical neck *occurring* at the time of attempted closed reduction [illegible]

[illegible] points up the extreme importance of gentleness in attempting manipulative *reductions*

## POSTERIOR GRADE III DISLOCATIONS

In our current series of patients who received destructive, explosive types of acetabular injury, the best results were in those who were treated surgically Their hips were reduced promptly and held in traction; then, at an appropriate time (usually several days later), the acetabular fractures were reduced and fixed with screws The posterior approach was used and any small, loose intraarticular fragments were discarded Immobilization in plaster or traction was continued in all of these patients for 5–6 weeks, vigorous muscle rehabilitation for all muscles about the pelvis, back and extremity were continually and religiously carried out However, the patients in the overall series who were treated *without open operation* gave a higher percentage of good results in all except the Grade III injuries

## DEATHS

There were ten deaths in this second series, but only two of these can be attributed to the dislocations One of these died of a cardiac arrest during the general anesthetic preparatory to manipulation Another died on the fourth postoperative day from an embolism following an open reduction The other eight died of extensive injuries to other parts of the body, such as head, chest, abdomen, liver, and other viscera These patients were suffering from excessive trauma and had an associated dislocation of the hip We do not believe that the dislocated hip in these eight patients was the cause of death

## CASE REPORTS

## DISCUSSION

The factors most responsible for poor results following fracture dislocation of the hip are

The severity of the initial trauma
The amount of delay between dislocation and reduction
The complications and the associated injuries
Repeated unsuccessful attempts at reduction
The age of the patient at the time of the dislocation

Nicol, reporting on 144 traumatic dislocations of the hip, and Brove on 264, stated that the time from dislocation and reduction to full

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In comparing the 222 hips studied recently and the 194 studied in 1952, the findings are quite comparable Certainly the basic principles of treatment remain the same

The importance of an immediate and correct diagnosis with prompt repositioning of the femoral head in the acetabulum is paramount

Gentleness in handling these severely injured patients and atrauma tic reduction of the hips are essential

After reduction, the hip must remain stable in the acetabulum In the Grade I dislocations this is usually no problem, but Grades II and III either posterior or central present a major challenge

In the Grade III posterior dislocation the best results are obtained by *prompt repositioning of the head, followed by open restoration* with internal fixation of the acetabulum

In the posterior Grade II's that are stable after reduction, protection by traction or body plaster for 6 weeks will usually ensure a good result

It is imperative that any and all fragments of bone or loose cartilage remaining in the hip joint after reduction be removed within the first few days

Those hips with Grade II or III central dislocations will respond best to adequate traction carried out over a sufficient period of time, usually 3 months

Hips with explosive injury to the acetabular dome will produce the poorest result

Lateral x-rays of the hips and pelvis are necessary for an accurate diagnosis

Immediate and accurate repositioning of the head in the acetabulum followed by internal fixation of the disrupted acetabulum when this can be accomplished simply, and fixation with two or three screws will give the best result However, in spite of Smith's & Knight's report we hasten to discourage open operation on those badly comminuted explosive types of inner wall acetabular fractures These can best be treated by prolonged skeletal traction applied in the longitudinal and lateral planes for a minimum of 3 months

The most neglected phase of treatment in fracture dislocation of the hip is proper, thorough, and prolonged muscle rehabilitation We have *found* repeatedly that the patient who must use his limb extensively in his daily activities during convalescence will invariably obtain the best functional result Also the best range of motion will be found in *the* plane of his maximum activity "The *function* of any joint after it has

been anatomically restored will return in direct proportion to the *strength* of the musculature which controls that joint"

## CONCLUSIONS

Dislocation and fracture-dislocation of the hip demand an accurate diagnosis and immediate reduction

Dislocations which are unreduced for more than 24 hours will produce unsatisfactory results

The age of the patient after the age of 15 has little or no influence upon the result

Lateral x rays of the hip are indicated in all dislocations and must be made whenever there is the least doubt concerning the accuracy of reduction or the position of any fragments

Open surgery for fixation of posterior acetabular fractures may be safely delayed for 7-10 days provided the femoral head is repositioned in the acetabulum and maintained by adequate traction

Severe inner wall fractures and explosive dome fractures of the acetabulum that are not suitable for open reduction (and very few are) can best be treated by skeletal traction This traction should be applied in both the longitudinal and lateral planes and continued for at least 3 months

Provided the acetabulum is stable, the period of time from reduction to weight bearing will have little or no influence upon the final result

Grade IV dislocations with fractures of the femoral head above the fovea should have immediate reconstructive surgery In those patients over 50 years of age a prosthesis or total hip is recommended, in younger patients a cup arthroplasty or an arthrodesis is sufficient

Avascular necrosis and degenerative arthritis develop in direct proportion to the severity of the trauma and the time of delay in reduction

Adequate rehabilitation of the muscles about the hip and lower limb is imperative if a good result is to be obtained

## SUMMARY

This report reviews two groups of cases 194 fracture dislocations of the hip reviewed in 1952, and a follow up of 222 additional fracture dislocations of the hip seen since then The report describes the methods of treatment used in terms of the various classifications of fracture

dislocations of the hip and analyses the results, the complications and the comparative results in these two groups of patients

Recommendations as to the proper form of management for each type of fracture dislocation are presented

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*Key words* fracture dislocation hip closed reduction open reduction time of reduction sciatic nerve

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Acta orthop scand 46, 526–547, 1975

# RESEARCH AND DEVELOPMENT WITHIN SURGICAL AMPUTEE MANAGEMENT

G Murdoch

A comprehensive view of the amputee and his medical care quickly reveals the multi-disciplinary nature of this field of medical activity, and a survey of the historical development reveals that many factors other than strictly medical ones have played equally important roles in improving the amputee's rehabilitation Accordingly, a comprehensive review of developments would inevitably touch on many subjects outside the scope of this study, which is focused on the amputating surgeon and his concern with causal conditions, techniques and levels of amputation, and the environment of the stump

## *Vascular disease*

Typically the patient is elderly and subject to other handicaps (Troup et al 1975) The disease affects the vascular tree to a varying degree and the effect of loss of nutrition to the tissues is difficult to measure Therefore, in the past, most of these patients were given high amputations to ensure early wound healing Mazet et al (1959) reviewed 1356 leg amputations in patients over the age of 55 and found that in only 10 per cent of these patients had prostheses been described It should be noted that 90 per cent of the amputations were above the knee Olejniczak (1967) reported on a similar group of patients and noted that 73 per cent had had amputations above the knee, and just under 10 per cent had received prosthetic treatment

One recent event has focused attention on the lot of the amputee, namely the advent of 'immediate post-surgical fitting" of prostheses The first record of this is Berlemont's (1961) report which emphasised improved wound healing, whereas Weiss (1966) of Poland underlined the maintenance of neuro-muscular patterns Experience at that time was largely with patients outside the geriatric range, but the Seattle experience (Burgess & Romano 1968) demonstrated its possible ap-

plication on elderly patients with atherosclerosis and diabetes. The technique has been successful in several centres and condemned outright by others, the use of the immediate post surgical applicance being blamed by the amputating surgeon for his failure to achieve healing in below the knee stumps. As workers began to analyse the problems presented, it became apparent that identification of the correct level of amputation, a careful surgical technique, the environment of the stump and the application of a total care programme are basic to successful rehabilitation.

*Selection of level of amputation*

Murdoch (1967), in discussing the ancillary methods of investigation, pointed out that arteriography always represents the vascular situation at a disadvantage. Burgess confirmed this view in a close analysis of those patients in his series who had arteriograms (Burgess et al 1971, Burgess & Romano 1971), there being no consistent relationship between the severity of vascular insufficiency and the failure of the below the knee amputation to heal.

We have been fortunate in that a number of physical scientists have begun to apply their skills to the investigation of biological situations and, as a result, a number of devices and techniques have been developed which suggest that real help can be gained in assessing levels of tissue viability. There has been, for example, a good deal of interest in blood flow and attempts to develop non invasive methods of investigation. Measurements of the volume changes in a limb, viz plethysmography, give a good measure of total blood flow and a variety of methods are available. However, Holstein & Lassen (1948) pointed out that in severe occlusions and in situations where the blood flow is very small, volume expansion is insufficient to stretch the strain gauge, thus depreciating its usefulness in a situation where very precise determination is required.

A good deal of work has been devoted to the build up or wash out of radioactive tracers and the most promising techn[illegible] by Sejrsen (1971), and showed the value of skin blood flow in determining levels of tissue viability. When flow rates above 1.5 ml/min per 100 g of tissue were recorded, the amputation generally healed. Of 29 patients subjected to amputation in a blind

study, 26 healed primarily The two failures had flow rates of 0 56 and 0 13 ml/min per 100 g of tissue Clearly in these two cases the amputation should have been performed at a higher level

Perhaps measurement of the skin blood pressure will offer more significant information regarding skin nutrition Holstein & Lassen (1974) employing a radioisotope clearance technique first described by Nilsen et al (1967) and Dahn et al (1967) were able to measure cutaneous *perfusion blood pressure This technique employs 4 iodo*-antipyrine tagged with ¹²⁵I or ¹³¹I mixed with an equal volume of histamine diphosphate in isotonic saline 1 per cent w/v to produce local vasodilation

Browse (1973) made the point that it is the blood supply *after* amputation that is important and indicated a number of factors such as surgical technique, oedema, thrombosis and infection as being significant Lassen & Holstein (1974), employing the technique mentioned above, made a further contribution to this problem They showed that five out of five amputations with a skin *blood pressure* below the 22 mmHg mark failed because of ischaemic necrosis Three out of 12 amputations with a skin blood pressure of between 20 and *40 mmHg again failed because of ischaemic necrosis, but none* of 34 amputations with a skin blood pressure above 40 mmHg failed In 11 subjects, wound healing occurred by secondary intention and it was *Lassen & Holstein's impression* that the delay often was related to poor skin circulation, especially where sutures had been placed Most of these cases exhibited a skin blood pressure in the 20–40 mmHg range If this is true, valuable information can be gained by a "pseudo-amputation", where the blood pressure cuff is inflated above systolic pressure level Using a photoelectric technique to determine skin blood pressure, the level was shown to be above 40 mmHg in 47 6 per cent *of 43 cases,* whereas the pseudo amputation technique revealed that 64 3 per cent of the same group had blood pressures above 40 mmHg This should be seen against results of estimations of those patients amputated in the so-called "safe" group, i e those who had levels over 40 mmHg *Before* amputation, 49 1 per cent of the patients were in this group, but after the amputation this group accounted for 63 4 per cent of the patients This approach *holds promise of providing a means of accurately* predicting the blood supply to critical tissues after amputation

Estimation of temperature remains a valuable technique in predicting tissue viability, whether it be by the examining hand, the thermocouple or as part of total heat emitted estimations by thermograph The

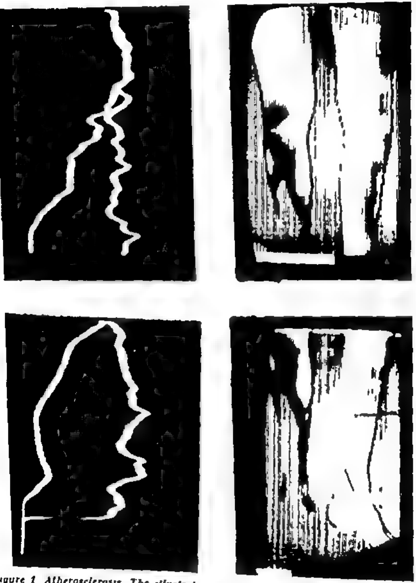


*Figure 1 Atherosclerosis The illustrations at the top show the situation in and around the knee and those at the bottom the situation at the foot and ankle On the left the trace records are demonstrated over a range of 6° C The case illustrated had had a right below-knee amputation It was felt that because of the ischaemia on the lateral aspect of the stump an amputation with a medial flap might have succeeded*

latter technique has not been fully explored and one factor which may have served to limit the use of this device is that most detectors operate within the range of 3 5–5 $\mu$m in a situation where the wave length of heat emitted by the human body is in the range of 0–20 $\mu$m with a mean of 10 $\mu$m A thermograph under test in Dundee has a detector operating within the range 6–14 $\mu$m and an example of a record is shown in Figure 1 Our experience suggests that it may provide information closely parallel to the state of the local skin blood supply The technique is, of course, non-invasive, causes no discomfort to the patient and may provide information not only about the level of amputation but about the orientation of skin flaps as well

*The diabetic foot*

Some 25 to 50 per cent of patients presenting for leg amputations with vascular disease suffer from diabetes The latter are often described as suffering from "diabetic gangrene". There is no such thing The pathology in the diabetic's foot or lower leg can be the result of small vessel disease, major vessel occlusion as in atherosclerosis in the absence of diabetes, neuropathy, or infections to which diabetic tissue is more prone All or some of these factors may be operating in a given case and thus each case must be assessed individually When there is not a major vessel occlusion above or below the knee, some diabetic feet can be saved by surgically excising all dead tissue, opening all infected areas and by careful pressure dressings and, if need be, local toe amputations and sometimes skin grafting Partial foot amputations and Syme's procedures may also offer feasible solutions for these patients Meggitt (1973) underlined these points in recording the management of 151 diabetic feet He showed that 18 per cent could be saved from higher amputation by a Syme's amputation performed in two stages, although a further 12 per cent required higher amputation The concept of a two-stage performance of the amputation was proposed first by Hulnick et al (1949) and later demonstrated as an advantageous method by Spittler et al (1954) in a series of 36 cases The technique is advocated for those patients with overt infection from whatever source, and Meggitt used it to good effect in his series It ensures a barrier of articular cartilage, and once the infection is controlled or the wound healed, removal of the malleoli can be performed These procedures will surely fail if the blood supply is inadequate due to proximal occlusions The preponderance of distal

pathology and the more frequent occurrence of major vessel occlusion below the knee will normally mean that the amputation need not be above the knee

*Trauma*

We all have to deal with traumatic injuries and it can be difficult to decide whether to amputate and at what level These past few years have seen no reduction in road traffic accidents and I regret to say there has been no shortage of wars Long established principles still hold, viz, to conserve all viable tissue, to close wounds where feasible, to employ open flaps where there has been much tissue destruction and where tissue of doubtful viability has been left, and to use a circular amputation in the presence of infection The Vietnam war experience provided solid affirmation of the need for skin traction in open amputations (Welch et al 1969, Mayfield et al 1972, Brown 1970)

Many amputations treated in this way will heal well and be fitted without more ado However, revision and stump reconstruction procedures should be seen as part of the natural history of the traumatic amputation The patient, prosthetist and surgeon should discuss thoroughly among themselves the patient's next 30–40 years of prosthetic wear to see whether any further procedures are desirable, e g excision of the fibula in very short stumps, osteomyoplasty (see below) or even simple excision of an adherent scar This sort of discussion should take place even when the patient is, for the moment, satisfactorily fitted

*Bone tumours*

Osteosarcoma continues to be the scourge it has always been, with a 5 year survival rate ranging up to little more than 20 per cent, regardless of the primary treatment employed Tragically, most of the patients involved are young adults, and within 2 years four out of five of them have died, usually from lung metastases

Dahlin & Coventry (1967) reported on 600 cases and confirmed the typical occurrence about the knee and that amputation remains the main weapon of treatment through the hip or sometimes the femoral shaft The report by Sweetnam (1973) suggests that while it is difficult to demonstrate improved survival rates, the higher amputation probably reduces the chance of local recurrence and its attendant misery Radiotherapy has not significantly improved the patient's chances

(Sweetnam et al 1971), although its application as recommended by Cade (1955) has spared many patients needless amputation by reserving the ablative procedure for those most likely to survive

In cases in which the metastases are disseminated, chemotherapy has not been very useful There has been some experience with the alkylating agents, none with nitrogen mustard and little with the antimetabolites Jaffé's (1972) report on the use of high-dose methotrexate with citrovorum factor and that of Cortes et al (1973) employing adriamycin in causing regression of pulmonary metastases created new interest, particularly as Marcove et al (1970) had shown clearly the close relationship between the occurrence of pulmonary metastases and death Further recent communications provide encouraging news of the use of chemotherapy given prophylactically immediately after amputation Jaffé et al (1974), using a combination of high dose methotrexate (with citrovorum factor) and vincristine, reported 11 out of 12 cases still free of metastases between 6 and 27 months after amputation Cortes et al (1974), using doxarubicin (adriamycin) *reported 10 out of 13 patients free of disease 9 to 40 months* after amputation Sutow et al (1974) used a four drug combination including doxorubicin and reported 10 out of 18 patients with no metastases 15 months after amputation, a later analysis of the same group of patients (Burchenal 1974) shows no recurrence in any of them 9 to 23 months after the cessation of chemotherapy—in all, between 27 and 40 months after amputation Clearly while this work may well presage a major breakthrough, further experience is required using combinations of a wide range of drugs in differing doses before the optimum can be *determined To ensure a sufficiently large case load to improve* validity it is necessary that as many centres as possible be involved It is to this end that the Medical Research Council of the United Kingdom has set up a working party to co ordinate a national trial of chemotherapy as prophylactic adjuvant treatment

Jaffe et al (1974) stress the importance of primary amputation and suggest that anything less may potentiate the development of resistant cells This will pose serious problems for those clinicians employing a regime of radiotherapy and delayed amputation Indeed it casts serious *doubt on* the efficacy of radiotherapy There will also be many problems with the inevitable side effects of chemotherapy—some serious and many certainly unpleasant Most clinicians will be happy to face up to these problems if the reward is 2 to 3 times the usual number of survivors

*Congenital limb deficiency*

Congenital limb deficiency is comparatively rare in the experience of any one surgeon and the management of these cases is perhaps best undertaken by special centres Even in these circumstances concern about a basic understanding of the nature of the defects and the difficulties in comparing methods of management has been expressed by a number of authors attempting to name and classify the defects This problem has been of interest to the Committee on Prosthetic Research and Development, National Academy of Sciences in the United States In order to promote international discussion and perhaps reach international agreement, the work of that committee and of professionals throughout the world was recognized in the formation of a Sub committee on Nomenclature and Classification in Congenital Limb Deficiency under the auspices of the International Society for Prosthetics and Orthotics Through the medium of a series of working groups, a measure of agreement has been reached which serves to overcome difficulties expressed in a series of publications A system has been evolved and has been exposed to an international field application study involving some 500 congenitally deficient limbs The proposed classification has presented little trouble in the great majority of these cases, but further work and trials are required to illuminate some of the problems presented In essence the system requires that all congenital limb deficiencies are to be classified as transverse or longitudinal deficits

1 *Transverse deficiencies* This category substitutes for the terminal transverse subsection of the Frantz/O Rahilly (1961), Hall (1962) and Burtch (1966) systems and the peromelia of the German nomenclature

Essentially, the defect presents as an amputation like stump In the proposed new nomenclature the deficiency is classified by naming 1) the level at which the limb terminates, or 2) the most proximal segment that is missing, it being understood that all elements distal to the level named are also absent The nomenclature for describing the appropriate level is reproduced in Figure 2 and the application of this terminology to one of the most common types of transverse deficiency is shown in Figure 3

2 *Longitudinal deficiencies* All skeletal limb deficiencies other than the transverse type are placed in the longitudinal category Thus, this subsection includes the terminal longitudinal, intercalary transverse, intercalary longitudinal and ectromelia subdivisions of previous systems

Transverse Limb Deficiencies (congenital amputations) With Suggested Abbreviations

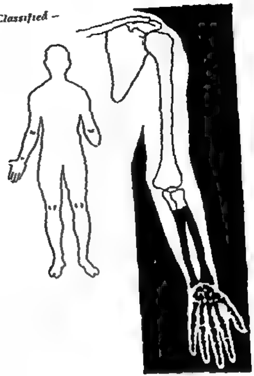
| UPPER LIMB (UL) | | LOWER LIMB (LL) |
|---|---|---|
| Shoulder (Sh) | Total | Pelvis (Pel) |
| Arm (Arm) | Total<br>Upper 1/3<br>Middle 1/3<br>Lower 1/3 | Thigh (Th) |
| Forearm (Fo) | Total<br>Upper 1/3<br>Middle 1/3<br>Lower 1/3 | Leg (Leg) |
| Carpal (Ca) | Total<br>Partial | Tarsal (Ta) |
| Metacarpal (MC) | Total<br>Partial | Metatarsal (MT) |
| Phalangeal (Ph) | Total<br>Partial | Phalangeal (Ph) |

*Figure 2 Language used in proposed classification*

In identifying deficiencies, all absent bones or portions of bones that are missing are named Any bones not named as being missing are understood to be present Figure 4 presents the application of the system to a fairly common longitudinal defect, while Figure 5 presents in chart form the language used in classifying this type of defect

It appears that none of the cases so far reported are unclassifiable under the system Some uncertainties remain and will be the subject of further work The World Health Organization is apprised of these developments and it is hoped that ultimately the system will be included in the International Classification of Disease If authors can be persuaded to follow the proposed nomenclature and classification, it will then be possible to compare reports and the body of knowledge collected will provide valuable statistical evidence as to trends and occurrence

*Figure 3 Typical transverse deficiency Classified – T-I Fo upper 1/3*



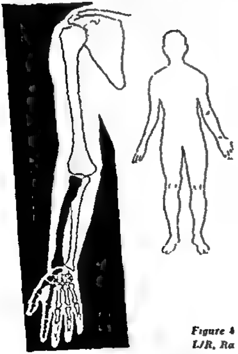


*Figure 4 Common longitudinal defect Classified – L/R, Ra total, Ca partial, Rays 1,2 total*

Transverse Limb Deficiencies (congenital amputations) With Suggested Abbreviations

| UPPER LIMB (UL) | | LOWER LIMB (LL) |
|---|---|---|
| Shoulder (Sh) | Total | Pelvis (Pel) |
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*Bone* Since the early German authors there has been continuing interest in the treatment of the bone end in amputation surgery and I am glad to record that authors now refer to sculpturing the bone end e g of the tibia and not to bevelling

Control of bone growth in relation to skin growth in the juvenile amputee is a continuing problem Swanson's work of implanting a silicone end prosthesis offers the possibility of avoiding repeated bone resections during growth In the same way osteomyoplasty should be considered for some of these children who have been subjected to below knee amputation instead of a procedure retaining the epiphysis but it is likely that an international trial will be required before any judgement can be made as to its efficacy

Osteomyoplasty as described by Ertl (1949) is in my opinion a positive contribution because it provides a stump which is uniquely tough It does not change shape socket changes are rare and it can sustain a measure of end bearing Regrettably there have been no long term reviews Deffer et al (1971) reported on 155 patients in whom this kind of operation was performed as a secondary procedure Only four failed and all others were successfully fitted

*Muscle* Early attempts at fixation of the muscles had the primary goal of providing a muscle pad Recently Dederich (1967) Weiss (1969) and Burgess & Romano (1968) have emphasised the need of securing fixation of the muscle units to the end of the stump bone Muscle stabilisation is claimed to be more physiological providing a more stable shape less muscle wasting better proprioception with retention of existing neuromuscular mechanisms more efficient vascular dynamics etc but few studies exist Dederich (1967) demonstrated improved vascular supply to the stump end after *myoplastic* revision and Hansen Leth & Reimann (1972) demonstrated in laboratory animals a better blood supply to the stump end when muscle stabilisation was used A small study in Dundee suggested that muscle stabilisation does give rhythmic phasic muscle activity on walking *in* contrast to the continuous but irregular pattern of EMG activity in un secured muscle (Figure 6) The advantages of muscle stabilisation in thigh amputations seem even more valid and perhaps more important in view of the interface conditions

*Nerve* Management of the divided nerve(s) and its inevitable neuroma has been a subject of controversy for more than a century The present practice of a high clean cut with the addition of ligature when necessary to secure intraneural vessels appears to be reasonably

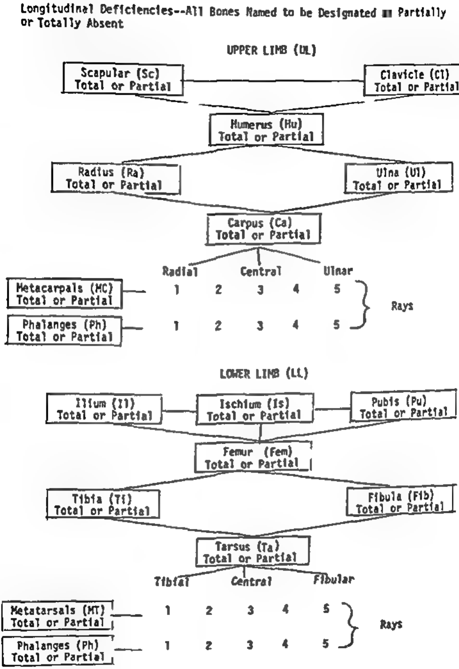


*Figure 5 Language and classification employed*

## *Surgical technique*

It is necessary to consider briefly the details of surgical techniques in amputation This in effect concerns management of the individual tissues

ally it consists of the use of fine intradermal interrupted sutures and steristrips

*Amputation levels* The value of the so-called end bearing stump such as knee disarticulation and the Syme's procedure have never been in doubt and have had recurrent spells of popularity Equally as often, there have been flirtations with other procedures, e g, transcondylar and supracondylar procedures at the knee, and the Emslie procedure at the ankle, because these procedures were more proximal and could more easily be fitted with a prosthesis that was cosmetically acceptable Many of these more proximal procedures still have their advocates, but most would prefer the knee disarticulation and the Syme's procedure if it were not for their cosmetic deficiencies The author (Murdoch 1975) has been faced with the same dilemma and on the basis of his clinical experience postulated that 'the classical Syme's stump when fitted with a modern prosthesis does not bear the full body weight on its end' The method employed was to undertake a direct measurement employing a dynamometer consisting of three pillars instrumented to measure axial loading only The dynamometer was securely fixed to the prosthesis spanning the narrowest point of the stump A cut was then made at that point, completely through the prosthesis and through any liner (Figure 7) The patient then walked and the signals from the device were transmitted to instrumentation consisting of amplifiers, a display oscilloscope and a two camera split screen videotape recording system The patient then walked over a force plate fitted flush with the surface of the floor, thus providing a measure of the total force transmitted from the ground to the prosthesis The signals from the

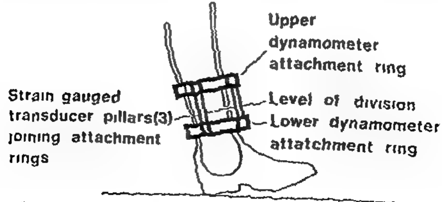


*Figure 7 Figure shows arrangement of dynamometer in relation to prosthesis*

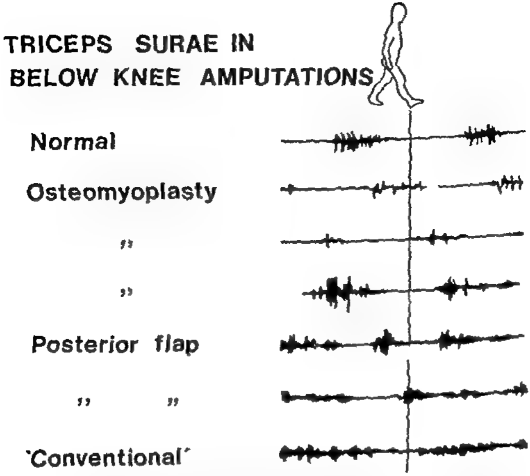


*Figure 6 EMG record of triceps surae in below knee amputees In the osteomyoplasty cases phasic activity is recorded approaching the normal In the first case there is additional activity immediately before heel contact (? acting as accessory knee flexor) In the posterior flap amputation activity is not so well defined and in the conventional amputation it is entirely random*

satisfactory Swanson et al (1972), basing their work on animal experiments, have shown in clinical practice that painful neuromas can be excised and the nerve capped with a silicone device to obviate recurrence They suggest with good reason that the technique could well be applied as a primary procedure

*Skin* A great deal of work has been done on the architectural nature of skin and its stress-strain relationships Certainly in the skin of the atherosclerotic patient and for every good reason in other patients, gentle handling and close apposition of the skin edges is necessary Browse (1973) proposed a technique which ensures precise apposition without the localised ischaemic effect produced by the suture Essenti-

ally it consists of the use of fine intradermal interrupted sutures and steristrips

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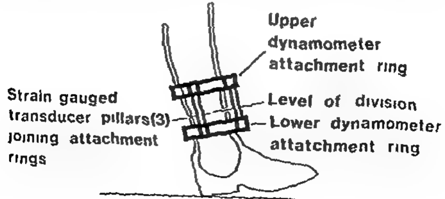
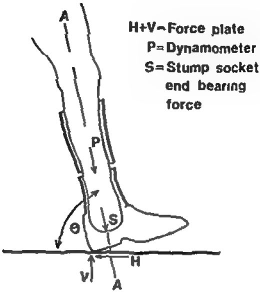



*Figure 7 Figure shows arrangement of dynamometer in relation to prosthes s*




For Equilibrium
The sum of the forces in the direction AA is zero

ie $\Sigma F_{AA} = 0$ ↑ positive

$\therefore \quad = -P-S+V_{AA}+H_{AA}=0$

$\therefore \quad = -P-S+V\sin\theta+H\cos\theta=0$

$\therefore \quad S = -P-V\sin\theta+H\cos\theta$

*Figure 8 Diagram illustrating forces involved and calculation required to demonstrate stump socket end bearing forces*

dynamometer provide a measure of that fraction of the total force which is transmitted to the upper part of the prosthesis and which must, therefore, be transferred to the upper part of the lower leg One of the video cameras gives a lateral view of the movements of the body segments, thus permitting direct measurement of angles, and the other is focussed on the oscilloscope displaying force records from force plate and dynamometer We are, therefore, in a position to relate the ground forces to the actual force lying in the axis of the leg at any instant in time There is now enough information to do what is, in effect, a subtraction and state the force actually transmitted through the end of the stump (Figure 8) A proportion of normal instrumentation errors can be eliminated by expressing the results as ratios of the total force transmitted through the end of the stump Figure 9 tabulates the results

# RESULTS OF FORCE PLATE/DYNAMOMETER STUDIES

Expressed as a ratio of the end bearing force to the total force acting down the long axis of the 'leg' during stance phase. (mid stance).

| | | |
|---|---|---|
| Subject AH | 47%<br>40% | All fitted with a Plastic Laminated Prosthesis |
| Subject JB | 73%<br>65% | |
| Subject AM | 49%<br>43% | |
| Subject LE (Child) | 75%<br>71% | Average |
| Subject CE | 34%<br>33% | 53% |
| Subject JM | 64%<br>62% | Side Bars Thigh Lacer |
| Subject JS | 88%<br>90% | Enclosed Metal Crustacean |

*Figure 9 Results of dynamometer studies Patients fitted with modern prostheses all show partial nature of end bearing Subject JM using traditional prosthesis uses heavy padding on his stump and very tight lacing Subject JS showing the highest degree of end bearing wore a prosthesis which did not intimately fit stump*

In my view there is enough evidence to show that the customary precise shaping of the modern laminated prosthesis to control rotations of the stump within the socket also *pari passu* causes significant force transference to the upper part of the leg, thus reducing end bearing This would suggest that it will be permissible to countenance reduction of the medial/lateral diameter of the stump end as practised by Mazet (1968) Bone removal is confined to the malleolar projections and the

reduction in area is estimated to be 12 per cent of the total area presented in a classic Syme's procedure It is our intention to employ an essentially similar method to test the end bearing properties of the knee disarticulation stump and, if the evidence permits, to modify the procedure without loss of its other attributes If successful, these modifications will allow the fabrication of more cosmetically acceptable prostheses

*Stump environment* A constant response to trauma, accidental or operative, is the formation of oedema and this effect is greater the more distal the wound The interstitial pressure may rise to a level where it may even affect the local blood supply, with the formation of more oedema, increasing pain and a real danger of forming a vicious circle The longer the oedema is permitted, the more difficult it is to dissipate, and where the blood supply is already precarious, interstitial pressure may be sufficient to produce ischaemia Accordingly, the environment of the stump after amputation may be critical to successful wound healing, especially in vascular cases

Historically this environment might consist of no more than a simple wound dressing or a variety of bandaging techniques It is not known how much bandage pressure the skin and subcutaneous tissues can withstand or for how long Isherwood (1975) in presenting a pneumatic bandage provides an excellent review of the subject as outlined here with Muller & Vetter (1954) maintained that sustained pressures in excess of 25 mmHg are potentially harmful Spiro et al (1970) discovered that a sustained pressure of above 15 mmHg decreased blood flow Intercapillary pressure varies with posture and in the recumbent position this is exceeded by externally applied pressures of 15 20 mmHg As the intercapillary pressure varies with posture, the ideal bandage should provide a graded pressure which is maximum at the most dependent distal point, decreasing proximally A hydrostatic bandage of this kind was described by Wood (1968) The situation is further complicated by the fact that, as shown by Husni et al (1968), pressures greater than 15 20 mmHg applied to the popliteal fossa created a tourniquet pressure effect even when the entire limb was wrapped Johnson (1972) believed that no dressing exceeding 10 mmHg should be left on overnight Redhead et al (1975), however, has beneficially applied to post-operative limbs cyclic pressures which did not drop below 25 mmHg Clinical experience certainly suggests that some bandages applied immediately post operatively have contributed to ischaemia of the stump Similarly, while trained staff can apply

bandages without detriment to the patient, it is often exceedingly difficult to teach the patient or relatives to repeat this performance Isherwood showed that the 'bandage' designed by Puddifoot et al (1973), which is essentially foam rubber pads within a sock, applied pressures of the order of 10 mmHg, although over some parts of the stump the pressures were as low as 5 mmHg and in unskilled hands pressures as high as 20 mmHg were imposed over other sites, particularly over the end of the stump

The application of a plaster of Paris cast has been an integral part of the philosophy of immediate post-surgical fitting since its inception Mooney et al (1971) presented the results of a study to define the place of a rigid cast dressing and early ambulation in the post-operative care of below-knee amputations secondary to diabetic vascular disease This was a strictly controlled study and showed that patients with a rigid cast as opposed to those with soft dressings healed faster

The protocol regarding weight bearing, that is to say, the application of forces to the stump generated by walking, has been modified with experience Weight bearing through a pylon attached to the plaster is now started later and applied by carefully controlled increments Mooney and his co-workers suggest that while there is good experimental evidence that gradual application of functional mechanical stress to healing connective tissue in an appropriate quantity and direction leads to a mature wound better equipped to tolerate the normal stress of function, it is apparent that ischaemic wounds tolerate only minimal stress in their healing phase Three papers are worth quoting in respect of early weight bearing, walking and exercise Larsen (1973) and Koppelmann (1973) both demonstrated that when muscle is exercised both in normals and in patients with occlusive arterial disease blood flow to the skin is decreased, i e, there is a diversion of flow to the exercising muscle and away from skin and non-exercised muscle This observation probably supports the view that weight bearing should be delayed On the other hand, Schoop (1973) stated that muscle becomes "trained" by exercise and demands a smaller increase in blood flow for a given load than does untrained muscle, leaving more blood available for less well compensated muscles and other tissues such as the skin This mechanism may in turn support the concept of a sustained exercise and early walking programme

One interesting and perhaps revolutionary solution to the problems of peripheral wound management is offered by Redhead (1974) He and his colleagues have produced a device which is essentially a trans-

parent bag which encloses the limb and at the same time permits air to escape via proximal skirting and does not allow any ingress except through a controlled supply. There is, therefore, control over pressure, humidity, temperature and sterility. The pressure can be applied within the range of 0–50 mmHg and can be controlled within precise limits and operate cyclically as desired. Of 28 hand cases treated in this way following operation, significant reduction in post-operative discomfort was noted and 10 had only oedema. Twelve amputee cases were treated in this way and none exhibited stump oedema, haematoma or wound infection; two required re-amputation because of muscle and skin necrosis and a third case involving electrical burns healed but later became infected.

Troup et al. (1975) demonstrated the value of a well organised programme of total care in describing the management of some 500 primary amputees. It is apparent that even when the surgery is performed by a variety of surgeons using different techniques and different stump environments, timely prosthetic fittings and integrated medical, nursing and physiotherapeutic care will ensure that nine out of 10 patients can be restored to significant independence and a "home" environment. It follows that scientific effort, improved surgery, an appreciation of the problems of stump environment and skilled prosthetics will not suffice. These must be supplemented by government or institutional investment in the provision of specialised units for care of the amputee.

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*Key words* amputation level, diabetic foot, limb deficiencies, skin blood pressure

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Acta orthop scand 46 549 560 1975

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# THE PATTERN OF NEW BONE FORMATION IN ISOGRAFTS OF BONE

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Accepted 13 1 75

After transplantation of autografts, or isografts, of fresh bone, new bone formation soon occurs The origin of this new bone is the subject of debate so that although some investigators will concede that it may to some extent be derived from osteogenic cells of the graft itself (Urist & McLean 1951 Ham & Gordon 1952, Hutchinson 1952, Ray & Sabet 1963 Puranen 1966, Bohr et al 1968), others claim that it is entirely derived by metaplasia of host cells (Barth 1893, Reynolds & Oliver 1949 De Bruyn & Kabisch 1955) Chalmers (1959) has suggested that in the case of some bone homografts there are two phases of osteogenesis an early phase in which the graft cells participate and which is cut short due to an immune response, and a late phase due to the activity of host derived cells In the case of isografts, however, no such distinction can be made using histological techniques

With the development of an objective radiochemical assay of osteogenesis it is possible to make a more dynamic assessment of the pattern of osteogenesis in bone grafts (Elves 1974) Using this approach it has been possible to show that there is evidence of *two phases of osteogenesis* in isografts of bone, that the early phase has a major graft contribution and that the second phase is host derived

## MATERIALS AND METHODS

Animals used as recipients in this study were 2 to 3 month-old (200–250 g) male rats of the AS inbred strain Grafts were of iliac bone containing bone marrow also from rats of the AS strain The attached muscle and the periosteum were scraped off before grafting Preserved grafts used in this study were frozen AS bone which had been stored at –20° C for 1 2 weeks freeze dried AS bone or AS bone which had been decalcified in HCl and then freeze-dried In some experiments fresh grafts were taken from donor AS strain rats which had been exposed to 650 or 850 rad x irradia

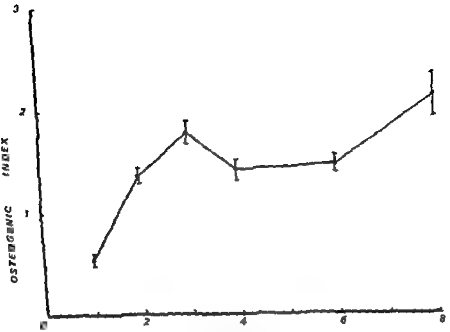


*Figure 1 The pattern of osteogenesis in isografts of fresh iliac bone (lines indicate S.E.) Osteogenesis equal to the skeletal level would give an index of 1*

The histological appearances of these cancellous grafts were essentially similar to descriptions given by previous authors (Chalmers 1959, Burwell 1964) They may therefore be summarised briefly New bone formation was evident by 7 days, by which time the intertrabecular spaces had become filled with granulation tissue and osteoid By ■ weeks the new bone was well mineralised and had expanded and now occupied many of the original intertrabecular spaces The original bone of the graft was by this time mostly dead By 3 weeks the abundant new woven bone was covered by a surface layer of osteoblasts and the spaces in the graft were in many cases showing development of bone marrow Over the next 5 weeks the graft became progressively smaller and assumed the appearance of an ossicle containing haemopoietic marrow Over this period too, the woven bone was gradually replaced by lamellar bone

Thus there is evidence from the $Sr^{85}$ uptake data of two phases of osteogenesis in bone isografts The histological method of assessing the grafts could not reveal these two phases A number of experiments

tion 24 hours earlier whilst in other experiments fresh isografts were exposed to 1200 rad x rays *in vitro* immediately prior to grafting. In order to assess the contribution of the graft marrow to osteogenesis marrow was removed from some fresh grafts by subjecting them to a stream of saline until they became white.

All grafts were placed into a suprapannicular pocket made in the skin of the dorsal surface of the recipient's thorax. Each rat received a fresh intact graft in addition to any of the preserved or treated grafts being examined. Grafts were examined after 1, 2, 3, 4, 6 and 8 weeks.

Osteogenesis was measured at each time interval using Strontium[85] as previously described (Elves 1974). Strontium[85] chloride was injected into rats by the intraperitoneal route 3½ days before killing. Results are expressed as an osteogenic index which relates isotope uptake in the graft to that in the cancellous skeleton of the host. It must be emphasised that this technique gives an assessment of osteogenesis over the short period of exposure to isotope and hence allows a distinction to be made between recent new bone formation and that which has occurred earlier (Elves 1974), a distinction which it is not possible to make using histological techniques. All grafts were also examined histologically after measurement of their contained radioactivity.

## RESULTS

### *Osteogenesis in fresh isografts*

One hundred and sixty three recipients of fresh marrow containing isografts have been studied. Between three and five experiments were carried out at each time interval and five or six animals were examined in each experiment. The results are summarised in Figure 1. From these results it is clear that the osteogenesis in most grafts (30/37) examined 2 weeks after grafting was in excess of that in the host's pelvis. The level of osteogenesis rose to a peak at 3 weeks by which time all grafts had an index of more than 1.0. A significant decline then followed. The mean index of osteogenesis at 3 weeks was significantly elevated compared with that at 2 weeks ($P \sim 0.01$–$0.001$). Osteogenesis seemed to reach a plateau between 4 and 6 weeks after grafting as the index was not significantly different between these points ($P = 0.7$). Six grafts out of 23 in the rats examined after 4 weeks and two out of 28 grafts examined after 6 weeks gave indices which were below 1.0. A second and significant elevation in degree of osteogenesis was found at 8 weeks ($P = 0.01$–$0.001$ compared with both the 4 and 6 week indices). Not all animals examined after 8 weeks however showed this increased level of new bone accretion. One group of 20 rats fell within two standard deviations of the 6 week mean value and in this group the mean index of osteogenesis was 1.54. The second group of eight rats had higher levels of osteogenesis and gave a mean index of [illegible].38

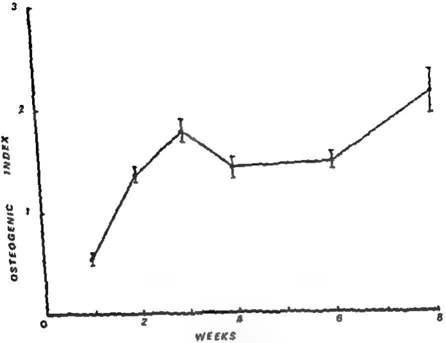


*Figure 1 The pattern of osteogenesis in isografts of fresh iliac bone (lines indicate S.E.) Osteogenesis equal to the skeletal level would give an index of 1*

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Thus there is evidence from the $Sr^{85}$ uptake data of two phases of osteogenesis in bone isografts. The histological method of assessing the grafts could not reveal these two phases. A number of experiments

have therefore been carried out in order to determine the nature of osteogenesis during the early phase in terms of host and graft contributions

*Osteogenesis in preserved bone grafts*

Three types of preserved bone grafts have been studied as mentioned above In the case of both freeze-dried and frozen grafts low levels of strontium uptake were observed at each time interval studied (Figure 2) It was not until 8 weeks after grafting that some grafts in this series exceeded an index of 0 30 which was recommended as the level of significance for uptake by calcium-containing grafts (Elves 1974) The mean index in both frozen and freeze-dried grafts examined after 8 weeks was significantly elevated above the indices at 6 weeks ($P =$ 0 01–0 001 and 0 05–0 01) Histologically, too, these grafts never showed new bone formation during the first 6 weeks, and only small amounts of new bone were present in a number of grafts at 8 weeks Thus these grafts are completely inert during the early phase, and in the majority of cases also during the later phase

The freeze dried calcium-free grafts also showed very low levels of strontium uptake over the first 4 weeks (Figure 2) The mean index in any group did not exceed 0 1 until 6 and 8 weeks after grafting After 3 weeks only two of 11 grafts had an index above 0 1 Histologically

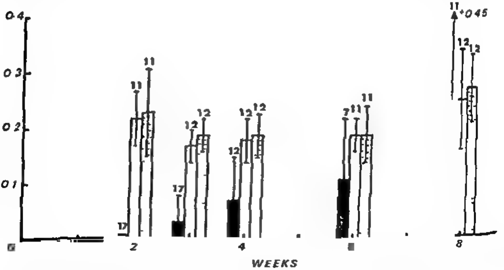


*Figure 2 Summary of data showing osteogenesis levels (± S F) in isografts of freeze-dried decalcified iliac bone (solid columns) freeze dried (open column) and frozen bone (stippled column) Number of grafts assessed shown above columns*

new bone was not seen in any graft removed up to 2 weeks after grafting, although many of these grafts showed invasion of matrix by chondrocytes and also small areas of cartilage development New bone was seen in small amounts in grafts removed after 3 weeks, usually associated with islets of chondrocytes It was not until 6–8 weeks after grafting that any extensive new bone was seen in and around these grafts In calcium-free grafts, therefore, the early phase of new bone formation was absent, although there was evidence of second phase osteogenesis

These experiments suggest a dependence on the graft for the early phase of new bone formation The graft contribution may be either in the form of osteogenic precursor cells or an "inducer" substance The preserved grafts used in these studies will certainly lack the former, and it may be argued that an inducer may be destroyed by the treatment

### *Osteogenesis in grafts of irradiated bone*

Three types of graft were studied for the first phase of osteogenesis (Table 1) Grafts irradiated *in vitro* with 1200 rad showed little osteogenic activity at either 2 or 3 weeks after grafting, and the difference between these grafts and normal control grafts was highly significant

*Table 1 Osteogenesis in iliac bone isografts subjected to x-irradiation prior to grafting*

| Exp no | Treatment of donor | Osteogenic index ± S E at* 2 weeks | 3 weeks | 7 weeks |
|---|---|---|---|---|
| 1 | None | 1 04±0 094 (9) | 2 08±0 20 (5) | 1.33±0 256 (6) |
| | 1200 rad *in vitro* | 0 21±0 005 (9) | 0 43±0 075 (5) | 0 74±0 113 (6) |
| | P** | 0 001 | 0 001 | 0 1 —0 05 |
| 2 | None | 2 19±0 170 (5) | 1 97±0 08 (6) | — |
| | 850 rad *in vitro* | 0 50±0 318 (5) | 0 63±0 03 (6) | — |
| | P** | 0 01—0 001 | 0 001 | |
| 3 | None | — | 1 32±0 07 (11) | — |
| | 650 rad *in vitro* | — | 0 56±0 05 (11) | — |
| | P** | | 0 001 | |

* Number of rats shown in parenthesis, each rat received one normal and one irradiated graft

** Student's *t* test

at both time intervals Only two out of nine grafts at 2 weeks, and three out of five examined after 3 weeks gave an index above 0 3 By 7 weeks after grafting a significant osteogenic index was seen in all grafts but in only one instance was the skeletal level of osteogenesis reached The difference between these grafts and normal control grafts was on the border line of significance Grafts irradiated *in vivo* with 850 rad all gave a measurable level of osteogenesis 2 and 3 weeks after grafting although none reached an index of 1 0 The grafts were significantly depressed compared with normal fresh grafts A similar significant depression in degree of osteogenesis was observed in grafts irradiated *in vivo* prior to grafting with 650 rad

These experiments clearly indicate the dependence of the early phase osteogenesis upon the cellular elements of the graft which must be viable

### *Contribution of marrow cells to early phase osteogenesis*

The osteoprogenitor cells may reside either amongst the population of cells lining the endosteal surfaces of the graft or amongst the cells of the bone marrow In order to assess the contribution of the bone marrow, osteogenesis in fresh grafts from which the red marrow had been removed were compared with fresh intact grafts, over the first 3 weeks after transplantation The results are shown in Table 2 Grafts devoid of bone marrow gave rise to levels of new bone formation which were *not significantly different from those in intact grafts* after both 2 and 3 weeks

***Table 2** The effect of removal of bone marrow upon the osteogenesis in fresh iliac bone isografts*

| Exp no | Type of graft | Osteogenic index at* 2 weeks | Osteogenic index at* 3 weeks |
|---|---|---|---|
| 1 | Marrow containing grafts | 1 55±0 118 (5) | 2 46±0 233 (6) |
| | Marrow free grafts | 1 81±0 161 (5) | 2 08±0 218 (6) |
| | *P*** | 0 7 | 0 3 |
| 2 | Marrow containing grafts | 1 59±0 120 (6) | 1 26±0 111 (6) |
| | Marrow free grafts | 1 50±0 190 (6) | 1 15±0 068 (6) |
| | *P*** | 0 70 | 0 40 |

* Number of rats shown in parenthesis each rat received one marrow free and one marrow containing graft

** Student's *t* test

## DISCUSSION

The bone grafts investigated during this study were placed in a subcutaneous site in order that the pattern of osteogenesis within the graft might not be confused by a fracture healing response on the part of the host. This would have inevitably followed the preparation of an osseous graft bed (Anderson et al. 1965, Puranen 1966). Thus an analysis of the relative contribution of host and graft to osteogenesis is possible, bearing in mind that the host contribution is not likely to be as great as in an osseous site.

By using $Sr^{85}$ for the assessment of osteogenic activity in the fresh cancellous isograft, two phases of osteogenesis are revealed. Histological examination of the grafts can give no indication of these two phases, being a static technique used to study what is essentially a dynamic process. The first phase reaches a peak after about 3 weeks, whilst the second phase occurs somewhat later in approximately one third of the recipients. It should also be stressed that even in those grafts which do not show a marked second peak of osteogenesis the level of osteogenic activity is approximately that in the normal skeleton. Chalmers (1959), in interpreting his histological observations of bone homografts, suggested an early peak in new bone formation during the second and third weeks after grafting, but this was followed by a decline and a second episode of new bone formation occurred 2 months later. Chalmers found that this second phase of osteogenesis was by no means seen in every homograft, and its incidence was of the order of 30 per cent. This figure is very similar to the incidence of late phase increased osteogenesis found in the present study of fresh isografts (8/28 = 28.6 per cent), and also to the incidence of osteogenic activity in grafts of dead bone (which is discussed later).

It is clear from the results presented above that the early phase of osteogenesis is dependent upon the viability of the graft. Thus freeze dried and frozen bone failed to show any early new bone formation. This finding is in agreement with those of others who have used histological methods to examine similar grafts (Ham & Gordon 1952, De Bruyn & Kabisch 1955, Haas 1957, Bonfiglio 1958). Puranen (1966), using the tetracycline marker technique, also found a severe impairment of new bone formation in frozen autografts placed in an intraosseous bed in rabbits, when compared with similar but fresh autografts. Thus in the preserved grafts osteogenesis did not begin until 3 weeks after transplantation and remained feeble. The same author

was able to show that osteogenic potential was lost from autografts if they were exposed to air, and presumably allowed to dry, for an hour Grafts kept in saline solution also lost their ability to form new bone rapidly after 3 hours of storage, 1 hour of such storage, however, did not affect the graft The latter two findings were confirmed by Bohr and his colleagues (1968) who placed preserved grafts in either intra osseous or intra-muscular sites, and also used tetracycline label to reveal new bone X-irradiation to the bone before grafting also abolished, or reduced, the early phase of osteogenesis as shown above These findings all point to the requirement for viable cells of graft origin for the initial establishment of osteogenesis

The second phase of new bone formation is, however, not wholly *dependent on the cellular population of the graft as there* is evidence of the second phase in grafts of irradiated bone examined after 7 weeks The host probably provides osteogenic precursor cells which become involved in late phase new bone formation However, descendents of *the original graft cells may also be active in some way in new* bone formation in fresh viable grafts during this period, because second phase osteogenesis is not as high in the absence of graft-derived new bone Puranen (1966) has presented evidence that an autograft of bone, if it is successful *in production of new bone, will also stimulate osteogenic* activity in the nearby host bone Inert preserved bone does not have this ability Thus it may be suggested that the newly formed bone has some osteo-inductive capacity upon the host cells

The late phase is also evident in decalcified freeze-dried *material* which showed a tenfold increase in $Sr^{85}$ uptake at 8 weeks compared with those examined after 3 weeks In the case of the decalcified grafts, strontium uptake was extremely low in most recipients This is due to the absence of calcium in the graft matrix and therefore *the removal of* the complication of "deep exchange" which may occur in mineralised bone (Elves 1974) All strontium uptake in these grafts is therefore due to new bone formed in the graft In four out of 11 recipients of decalcified grafts the osteogenic index was above 0 1 at 8 weeks Thus, it seems that the second phase of osteogenesis is established in only approximately one third of the recipients by 8 weeks In the freeze-dried and frozen grafts the evidence for late osteogenesis is less convincing However, with both materials, grafts are found *which show* an index of osteogenesis of 0 3 or above after 8 weeks (3/12 in the freeze dried, 5/12 in the frozen) Thus it may be concluded that the biphasic pattern of new bone formation found by Chalmers (1959) in homo-

grafts also occurs in isografts of cancellous bone but is not revealed by histological techniques

The origin of the new bone appearing in bone grafts has been a matter of dispute for some years Thus, on the one hand, there is the school of thought which holds that cells of the autograft bone itself do not survive, and therefore do not contribute to the new bone, which is produced from connective tissue and other cells of the graft bed (Barth 1893, Reynolds & Oliver 1949, De Bruyn & Kabisch 1955) According to this school the bone graft dies and, as it becomes necrotic, liberates substances capable of transforming mesenchymal host cells into osteogenic cells (Levander 1938) On the other hand there are those who hold the view that osteogenic cells in the graft do survive, proliferate and can give rise to new bone formation (Abbot et al 1947, Hutchinson 1952, Ham & Gordon 1952, Campbell et al 1953, Puranen 1966, Bohr et al 1968) Others adopt the view that the new bone arises both by activity of cells in the graft and also by osteoinduction by the graft from host mesenchymal cells (Urist & McLean 1951, Ray & Sabet 1963) The results obtained during the present study indicate that the latter view is most probably correct First phase osteogenesis clearly has a major graft component, as it is almost completely abolished in dead grafts

It may be argued, however, that x irradiation, freezing or drying may destroy the graft s capacity for osteoinduction in the host In answer to this criticism it is pointed out that in the present study second phase osteogenesis is evident, although poor, in some of these non viable grafts Chalmers and his colleagues (1959) have also found histological evidence of new bone formation in freeze dried and frozen grafts and also in freeze dried bone exposed to high doses of irradiation Similarly, Burwell (1966) has reported that frozen, *freeze-dried and heavily irradiated* homografts of bone all retain their ability to induce new bone formation in autologous bone marrow in composite homograft/autografts

It may be suggested therefore, that *osteogenesis in autologous or* isologous bone grafts is initially derived from cells in the graft which rapidly proliferate and form new bone Host cells then enter the graft and are induced by the graft to become osteogenic, and these too will ultimately contribute to new bone formation in the graft Thus the latter part of the first phase is probably of mixed graft and host origin To what extent the host contribution is dependent upon the initial graft derived osteogenesis is not clear, although it is found that second

was able to show that osteogenic potential was lost from autografts if they were exposed to air, and presumably allowed to dry, for an hour. Grafts kept in saline solution also lost their ability to form new bone rapidly after 3 hours of storage; 1 hour of such storage, however, did not affect the graft. The latter two findings were confirmed by Bohr and his colleagues (1968) who placed preserved grafts in either intra-osseous or intra-muscular sites, and also used tetracycline label to reveal new bone. X-irradiation to the bone before grafting also abolished, or reduced, the early phase of osteogenesis as shown above. These findings all point to the requirement for viable cells of graft origin for the initial establishment of osteogenesis.

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Another enigma surrounds the identification of the cells in the graft which have osteogenic potential Clinically it is of some importance to solve this problem in order to preserve these cells in bone used for transplantation Many authors agree that survival of endosteal and periosteal cells after grafting is possible and that these cells are important for new bone formation (Lacroix 1951, Ham & Gordon 1952, Hutchinson 1952, Urist & McLean 1952, Campbell et al 1953, Bonfiglio 1958, Burwell 1964) Certain cellular components of the bone marrow have also been suggested as osteogenic precursor cells Bone marrow undoubtedly has osteogenic potential when used as an autograft (Levander 1940, Urist & McLean 1952, De Bruyn & Kabisch 1955, Burwell 1964, Plenk et al 1972, Salama et al 1973) From the data presented above it would seem that under the conditions of these experiments the bone marrow is not a major source of osteoprogenitor cells, as its removal has no significant effect on the early phase of new bone formation

## SUMMARY

The pattern of new bone formation has been studied in isografts of fresh iliac bone and also in isografts of dead or irradiated iliac bone Two phases of osteogenesis have been found in some fresh grafts An early phase occurs during the first 3 weeks after transplantation whilst the second phase is found after 8 weeks The first phase is absent from non-viable grafts and it is therefore concluded that cells of the grafts are largely responsible for this early osteogenesis The second phase, it is suggested, has a major host component, and may be due to induction of osteogenic potential in host mesenchymal cells There may be some dependence of the second phase on the first but the extent is not clear Removal of the bone marrow from the graft has little effect upon the first phase of new bone formation and it is suggested that surviving endosteal cells are the main participants in early osteogenesis

## ACKNOWLEDGEMENTS

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Acta orthop scand 46 561 568 1975

Department of Orthopaedic Surgery University J E Purkyně Brno

# THE MORPHOLOGY OF GROWTH CARTILAGE USING THE SCANNING ELECTRON MICROSCOPE

Z BOZDĚCH & V HORN

Accepted 2 1 75

The growth cartilage remains the centre of attention of many authors (Sundén 1967) The possibility of its observation using the transmitting electron microscope has been an outstanding scientific advance (Trueta 1968) However, due to the complicated spatial organization of the growth cartilage, information on the three-dimensional configuration, which would objectively show the morphology of epiphyseal growth has been missing This can be afforded by scanning electron microscopy (Horn et al 1972 Fujita et al 1971, Kohler 1973) as used by the present authors who studied an experimentally induced traumatic epiphyseolysis in rabbits

## MATERIAL AND METHODS

The authors carried out their experiments on 20 domestic rabbits (albinos) 4 weeks old The distal ends of the femurs were isolated immediately post mortem by rapid dissection and bent to imitate the separation of the epiphysis Both ends of the specimens were immediately fixed in 10 per cent formaldehyde and then dehydrated in acetone of graduated concentrations Finally they were adhered to an observation table and shadowed with gold using a Balser apparatus The specimens were then observed under the scanning electron microscope (Cambridge) 10–25 000 × magnification The specimens were fixed simultaneously, and studied by the usual histological methods

## FINDINGS

The transverse break of the epiphyseal plate most often ran through the area of hypertrophied cells To obtain other sections of the epiphyseal plate in the break, the authors were obliged to break a larger number of specimens and sometimes even cut the cartilage in the appropriate zone before breaking II Thus they managed to obtain breaks of different layers, for example, the layer of proliferating cells,

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*Key words* bone grafts osteogenesis Strontium$^{85}$ bone growth transplantation

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Acta orthop scand 46 561–568 1975

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*Figure 1 A longitudinal section of epiphyseal cartilage with a layer of proliferating cells and the cells of the hypertrophic zone above × 160*

the germinal layer of cells, or the boundary between the germinal and terminal plates

In some cases the line of epiphyseolysis ran first horizontally and then continued vertically, parallel with the column of cells, as is seen in clinical practice (Holland's triangle—Blount 1955) These longitudinal breaks give a clear picture of the chondrocyte structure as well as the collagen structure of the matrix (Figure 1)

There can be seen many impressions of various depths, originating from previously attached chondrocytes of the germinal zone and appearing on the border of the terminal plate Where some of these cells of the germinal zone remained attached to the terminal plate, they were easily distinguishable from the neighbouring empty lacunae In other places the impressions (Figure 2) occurred as honeycomb-like structures, creating the basis for the columnar arrangement of the chondrocytes in further layers of the growth cartilage

The proliferative zone in the longitudinal break showed a great gathering of inset and flattened chondrocytes (like piled coins) (Figure

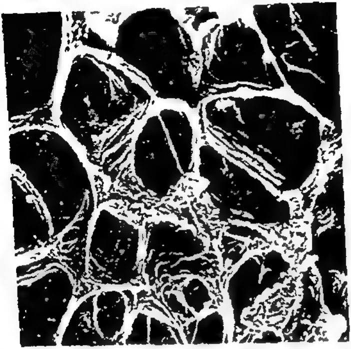

*Figure 2 Honeycomb like structure of the intercellular matrix in the epiphyseal part of the growth cartilage in the area of the germinal cells × 1 600*

3) The transverse septae were strikingly narrow, whereas the longitudinal ones were markedly wider Numerous protruberances occurred on the surface of the flattened chondrocytes by which they are anchored to the wall of the lacunae Further towards the metaphysis, the chondrocytes enlarged and the transverse septae became more marked The chondrocytes took on a spherical or oval shape and their attachment to the wall of the lacunae was clearly seen Here (in the longitudinal breaks) the passage of collagen fibres in the intercolumn and transverse septae was well manifested (Figure 4) When the longitudinal break did not run directly through the column of chondrocytes but through the septum, the lacunae occurred as protruberances of the collagen matrix In some of these breaks it was found that the cells remained in the other part of the specimen and that the lacunae were empty Here the structure of the lacunae was particularly well seen

In the zone of degenerating chondrocytes (in the zone of capillary invasion) empty lacunae occurred, thus forming, by resorption of the transverse septae, connecting tubular spaces without any remnants of

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*Figure 4 A longitudinal break through a cartilage cell column of the epiphyseal cartilage closer to the metaphysis The cells are more swollen, the transverse septae are thinner × 3,160*

matrix is relatively thin and calcified between the hypertrophic cartilage cells The calcification influences and organizes the penetration of the metaphyseal vessels into the bone plate, thus effecting enchondreal ossification This layer of the growth cartilage is at the same time also the most frequent site of traumatic epiphyseolysis, which again, under certain conditions, can exert an unfavourable influence upon the further development of the damaged epiphyseal cartilage

Each layer of the growth cartilage, including the sites of epiphyseolysis, were observed by scanning electron microscopy This method clearly showed the course of the collagen fibres in the longitudinal (intercolumnar) and transverse (intercellular) septae Especially clear is the gradual disappearance of the transverse septae towards the metaphysis

The chondrocytes send out a number of protruberances directed towards the wall of the lacunae on which there are correspondingly reflected depressions The terminal bone plate appears as an isolated and

*Figure 3 The proliferating zone of the epiphyseal cartilage with columns of cartilage cells and typically arranged intercellular substance × 2 500*

the chondrocytes (Figure 5) In some columns net-like structures occurred partly containing erythrocytes, which may be considered as vascular areas (Figure 6)

## DISCUSSION

The organization of the epiphyseal growth cartilage is the consequence of complex evolutionary processes already originating in the skeletal cartilage This organization, however, enables the longitudinal growth of the bone in spite of the mechanical load, the rather unfavourable nutritive conditions (Trueta 1968), the influence of pressures in the growing bone, and also in spite of the action of the surrounding muscles, which do not always work evenly and rectilinearly The fertility of the cartilage cells depends on the number of cells in the column The terminal cartilage cells on the metaphyseal side are swollen and are gradually replaced by vessels, loops of the metaphyseal capillaries, which form the borderline of erosion The intercellular fibrillar

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*Figure 6 Capillary spaces with blood cells in the zone of capillary invasion* $\times$ 1 460

## CONCLUSIONS

It may be said that the method used by the authors improved the spatial image of each layer of the growth cartilage and explained the mechanism of traumatic epiphyseolysis in places of least mechanical resistance in the plate From these pictures it also follows that insufficient treatment of epiphyseolysis may very easily reflect itself in defects of the enchondral growth of the bone

## SUMMARY

The authors undertook a scanning electron microscopic study of the layers of the growth cartilage in the distal end of the rabbit femur in longitudinal and transverse fractures The relationships between the various morphological structures were determined The three dimensional spatial depiction facilitates the better understanding of some mutual relationships between various growth cartilage components Especially interesting are the regressive processes in both the cells and the matrix which explain the reduction of mechanical strength in the

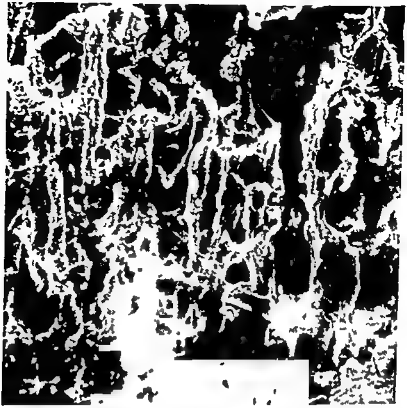

*Figure 5 The degenerative zone showing only the remnants of the longitudinal intercellular septae × 350*

separate structure onto which, however, cartilaginous elements (germinal zone of the epiphyseal cartilage) continually attach themselves

The degenerating cells with the invading capillaries proved to be the most interesting layer Here originate the wide tubular cavities, in between which the remaining matrix is fairly thin and is represented by remnants of the septae This explains why this zone is mechanically also the most labile and why it has the highest frequency of traumatic epiphyseolysis Here the matrix loses its fine granular or fibrous character (as shown by the breaks in the proliferating cartilage) and takes on a more homogenous bone-like appearance By scanning electron microscopy it is not possible, of course, to determine whether it is bone or calcified cartilage and this complicates the more precise differentiation of the primary zone of calcification This area would call for further study, especially in regard to the exact spatial arrangement of the remaining septae and cartilaginous cells in relation to the penetrating vessels

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*Key words* growth plate epiphyseolysis morphology in scanning electron microscopy

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Acta orthop scand 46, 569 578, 1975

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# STRONTIUM-85 PROFILE COUNTING IN FRACTURES OF THE TIBIAL SHAFT

J Puranen, K Kiviniitty & P Kaski

Accepted 28 iii 75

**The purpose of the present study was to evaluate the uptake of strontium in cases of fracture of the tibial shaft displaying normal healing, delayed union and non-union, and to suggest the clinical significance of the findings**

## MATERIAL AND METHODS

A total of 203 strontium profile countings were made on [illegible] fractures of the tibial shaft in the Clinic of Surgery, University of Oulu One injection of strontium was given in 441 cases, two injections at different stages of the healing process in 22 cases and three injections in five cases Of these fractures, 25 displayed normal healing 37 displayed delayed union, and six displayed non union

The method employed was strontium 85 profile counting According to Taskinen & Vahatalo (1971) this technique clearly provides more accurate information than scanning

Strontium 85 was administered intravenously in doses of 50 $\mu$Ci of strontium chloride The measurements were made on an NaI(Tl) scintillating counter with a circular collimator 3 cm in diameter The assays were performed on the 7th, and in 19 cases also on the 1st day after the injection of strontium. When the strontium 85 countings were made on the day after the injection of strontium, the percentage ratios (fracture/control) were low in comparison with the values obtained a week later (Figure 1) The readings were obtained from the leg at intervals of 3 or 5 cm and compared with the corresponding values for the healthy leg The results are given as percentages of the values for the healthy leg In addition to this, control measurements were made on each thigh at the inguinal fold and at 5 cm from the upper edge of the patella If there was a plaster cast on the fractured leg, the healthy leg was also measured through a cast

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*Key words* growth plate, epiphyseolysis, morphology in scanning electron microscopy

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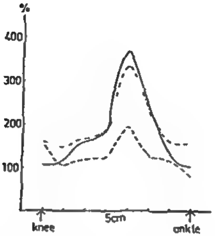


*Figure 1 Transverse fracture of the tibial shaft which healed in 4 months Strontium-85 injection was performed*

------ 4 weeks after the injury (measured one day after the strontium injection)
– – – 4 weeks after the injury (measured one week after the strontium injection)
——— 6 months after the injury (measured one week after the strontium injection)

RESULTS

*Normally-healing fractures*

Normally-healing cases included the fractures of the tibial shaft which were united within 6 months 25 cases out of the total series healed normally Strontium-85 counting was performed at different stages of the healing process from the first days up to six months (Figure 2) In two cases the measurements were made as much as 2 years after the fracture

When a fracture occurred, the uptake of strontium at the site of the fracture began to increase, though slowly at first During a month after the injury, 21 profile countings in all groups showed that within the first few days strontium uptake was hardly elevated in comparison with the control leg One week after the fracture the values were 160–180 per cent, even in delayed union In normally-healing cases, as early as after 3 weeks the uptake of strontium increased to over 300 per cent The peak values occurred after 4 6 months, being then of the order of 400 per cent After 2 years the strontium accretion at the site of the fracture was still elevated (140–150 per cent)

The average activity percentage for all cases of this group was 485 Figure 1 shows the typical curves for strontium uptake High accretion of strontium was visible at the site of the fracture after 4 weeks and 6 months Measurements performed on the day following the strontium

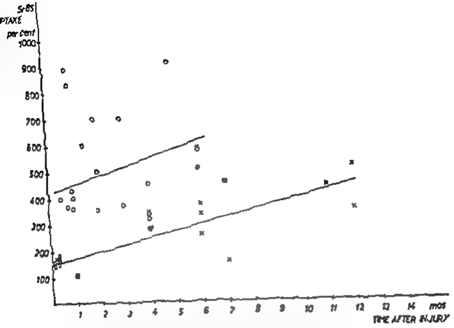


*Figure 2* *Regression lines indicating strontium uptake in fractures of the tibial shaft*
○ strontium uptake of one fracture with normal healing
× strontium uptake of one fracture with delayed union treated conservatively
ȯ ⊡ ⊗ strontium uptake of same fracture at different times

injection showed the relative strontium uptake to be clearly less intensive

### *Delayed union*

The healing of a fracture was regarded as delayed when it took more than 6 months This group consisted of 37 fractures, 9 of which were treated conservatively and 28 by bone grafting The choice of treatment was made on the basis of osteomedullography (Puranen & Kaski 1974)

The fractures treated conservatively were surveyed at different stages of the healing process Although this group is too small to enable significant conclusions to be made, Figure 2 suggests, however, that the regression line indicating strontium uptake went distinctively lower in this group than in normally healing cases, but in both groups the slope of the line was the same The average activity percentage was

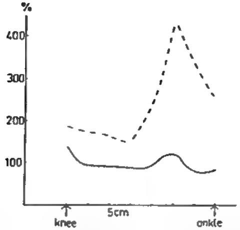


*Figure 3 A fracture which healed in 9 months Strontium 85 injection was performed*
——— 4 weeks after the injury (measured one week after the strontium injection)
– – – 7 months after the injury (measured one week after the strontium injection)

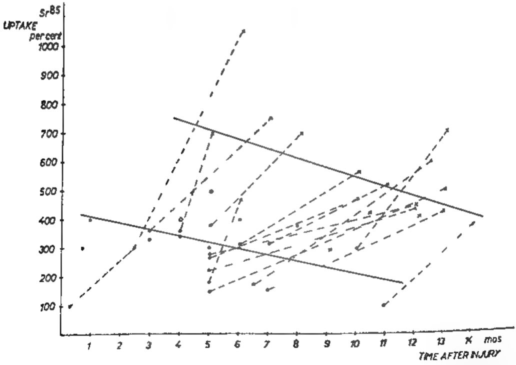


*Figure 4 Regression lines indicating strontium uptake in fractures with delayed union treated by bone grafting*

○ strontium uptake before bone grafting

× strontium uptake after bone grafting

Dotted line unites the measurements of same fracture Background counts of the strontium uptake before bone grafting are subtracted

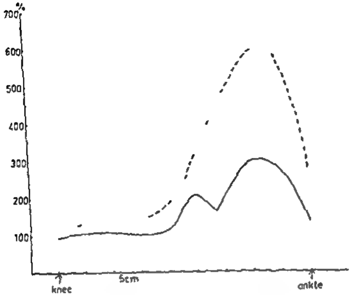


*Figure 5 Transverse fracture of the lower part of the tibial shaft with delayed union*
——— Measured 1 day before bone grafting (5 months after the injury)
- - Measured 3 months after bone grafting

290 Figure 3 shows the uptake curves for a case of delayed union at 4 weeks and at 7 months after the injury At 4 weeks the activity percentage was quite low, but at the stage where the progress of union could also be observed clinically, the percentage was clearly higher The union was complete 9 months after the injury In these cases the uptake of strontium was, 4 years from the date of injury, still as high as 350 per cent, although the leg was symptomless and perfectly consolidated

In the 27 fractures which required bone grafting, most of the strontium countings were made just before the operation and about 3 months after it In 15 cases the uptake of strontium was measured pre- and postoperatively (Figure 4) The mean activity percentage of strontium was 300 before the operation and 700 afterwards

A typical example of the distinct increase of strontium accretion occurring after the operation is seen in Figure 5 Figure 6 shows a very high strontium uptake at the site of the fracture recorded 5 months after the injury and 3 weeks after bone grafting The region of the knee had a similarly high strontium uptake due to a fracture of the fibular head The region of the tibial fracture still displayed a fairly high

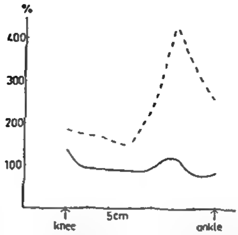


*Figure 3 A fracture which healed in 9 months Strontium 85 injection was performed*
——— 4 weeks after the injury (measured one week after the strontium injection)
–·– – 7 months after the injury (measured one week after the strontium injection)

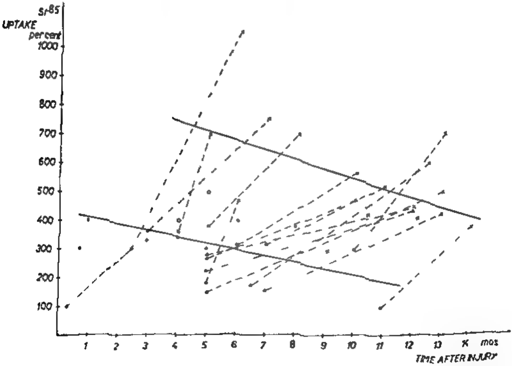


*Figure 4 Regression lines indicating strontium uptake in fractures with delayed union treated by bone grafting*

O strontium uptake before bone grafting

× strontium uptake after bone grafting

Dotted line unites the measurements of same fracture Background counts of the strontium uptake before bone grafting are subtracted

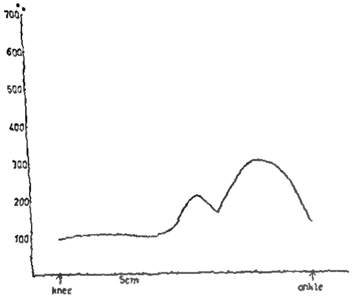


*Figure 5 Transverse fracture of the lower part of the tibial shaft with delayed union*
——— Measured 1 day before bone grafting (5 months after the injury)
Measured 3 months after bone grafting

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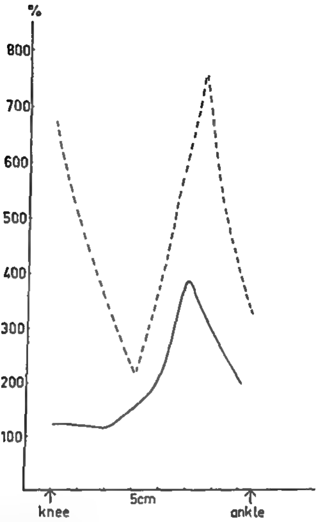



*Figure 8 Transverse fracture of the tibial shaft with delayed union and a fracture of the fibular head with normal healing Bone transplant performed 5 months after the injury Strontium 85 counting was performed*
- - - - 3 weeks after bone grafting
——— 19 months after bone grafting

strontium uptake 24 months after the fracture, while a normally-healed fracture of the fibula at that time uptook no more strontium than did the fibula of the control leg

In the group of fractures with delayed union, strontium uptake at the site of the fracture was still elevated four years from the date of injury Profile counting was made in five cases after 1 5–3 3 years from consolidation, and the activity values were over 200 per cent (range 150–450 per cent)

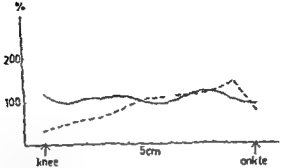



*Figure 7 A 7 year old girl with congenital pseudarthrosis of tibia The measurements were performed before and after bone grafting Strontium counting was made*
——— 2 days before the bone grafting
2 months after the bone grafting

*Non union*

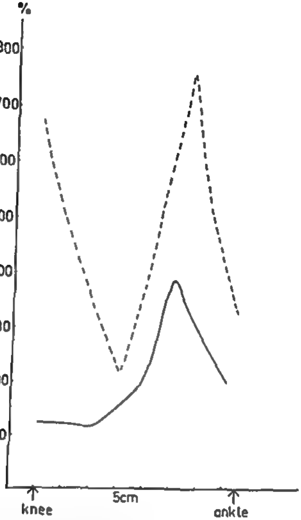
One year was arbitrarily chosen as the length of time after which the unhealed fracture was considered as a case of non union This series included two hypertrophic and four atrophic cases of non union

In both hypertrophic cases strontium uptake was preoperatively high (300 per cent) Bone grafting led to consolidation within 3 months In atrophic pseudarthrosis on the other hand strontium accretion was hardly elevated in comparison with the healthy leg as measured preoperatively

This group included one 4 year old and one 7 year old girl each with congenital pseudarthrosis of the tibia Their strontium counting displayed no difference between the fractured and the healthy leg either before or after bone grafting In both cases the transplantation failed and the bone graft was resorbed (Figure 7)

The third case was a non union following suppressed osteitis and its strontium uptake was small (150 per cent) Bone grafting did not lead to consolidation but it caused the leg to stabilize sufficiently to enable the patient to walk with support Strontium uptake 2 years after the first bone grafting revealed a marked difference in comparison with the healthy leg (600 per cent) A new bone grafting succeeded and pseudarthrosis consolidated within 3 months

The fourth patient of the group also had a large bone defect associated with osteitis Strontium uptake after suppressal inflammation revealed an activity value of 140 per cent Bone grafting was performed

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healing process. The cases of delayed union treated conservatively showed higher uptake during the existence of roentgenographic signs of consolidation than before that, when the necessity of bone transplantation was considered (Figure 6). On the other hand, in the cases which required operation for union the healing process was retarded and bone transplantation was intended as an osteogenetic stimulus to consolidation. The bone transplant was found to have a very distinct effect on the increase in the local mineral metabolism, which is shown by high strontium uptake immediately after the bone grafting (Figure 3). This lends further support to the observations made in the case of immediately transplanted bone (Puranen 1966).

The high strontium uptake at the site of the fracture means that the local osteogenetic activity of the fracture has increased. This, however, does not guarantee that the fracture will heal normally as also stated previously by Bohr (1955) and Wendeberg (1961). Although there were differences in strontium accretion between the cases of normally healing fracture and delayed union in the present investigation, they were not sufficiently pronounced to allow classification of individual fractures into different groups.

In the cases of hypertrophic pseudarthrosis, strontium uptake was increased indicating lively mineral metabolism. Bone grafting is the osteogenetic stimulus which is needed by fractures with non-union in order to consolidate. In atrophic pseudarthrosis, on the other hand, hardly any difference was seen in strontium uptake between the fractured leg and the healthy one. In such cases bone grafting did not increase strontium activity as it usually did, and the transplanted bone was even resorbed as in congenital pseudarthrosis of the tibia. The cases of non union in our series showed that unless the activity ratio was high enough, the bone grafting did not lead to consolidation, not at the normal rate anyway. Segmuller et al. (1970) have also pointed out that strontium assay serves as a parameter of local mineral metabolism in estimating the local osteogenetic capacity of non-union. The real clinical significance of strontium counting in fractures thus lies in the fact that it helps in estimating the prognosis in fractures requiring bone transplantation.

but no consolidation was seen until after 9 months, whereas it usually occurs within 3–4 months

## DISCUSSION

The present work showed that the difference in activity percentage between the fractured leg and the control leg increased as much as two- or threefold when the measurement performed on the day following the injection of strontium was repeated one week later This is understandable, since during the first few days strontium also appears elsewhere besides being aggregated in the bones The readings obtained during the first day are therefore merely indicative, and it is advisable to perform the strontium counting a week after the injection

When a fracture occurred, circulation began to increase at the site of the fracture, and many times did so even in the whole of the lower limb This was for example indicated by the elevated strontium activity of the lower limb, the average value being 130 per cent The metabolism of the fractured bone was similarly accelerated The measurements revealed distinct strontium uptake (approx 180 per cent) at the site of the fracture 1 week after the injury After 2–3 weeks the normally healing fractures began to display considerably elevated values, which reached their peak 4–6 months after the injury (400 per cent)

Elevated strontium accretion (approx 150 per cent) at the site of the fracture was still perceptible as much as 2 years after injury Cases of delayed union which healed with or without bone grafting displayed a fairly slow decline in strontium-85 activity, values over 200 per cent and even 400 per cent being obtained 2 3 years after consolidation of the fracture

The present investigation gave evidence in favour of the view of Wendeberg (1961) that the ratio of strontium activity in the fracture during the healing process was consistently elevated irrespective of whether the case was a delayed union or healed normally In the latter case, however, the ratio was higher than in delayed union Even alkaline phosphatase activity, according to Gudmundson and Semb (1971), is significantly depressed in cases of delayed union as compared with normally healing fractures

The regression lines (Figures 2 & 4) of the fractures with delayed union prove that the strontium uptake rose as function of time in conservatively treated fractures, but fell in fractures needing bone grafting The explanation may be found in the progression of the

Acta orthop scand 46, 579-592, 1975

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# BONE LESIONS IN PIGMENTED VILLONODULAR SYNOVITIS

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Accepted 7 iii 75

Pigmented villonodular synovitis is a rather rare disease affecting the synovial membrane of various joints, bursae and tendon sheaths It may appear in either a diffuse or a localised form The aetiology of this condition is unknown, although various theories have been postulated, such as repeated minor trauma to the synovium (Greenfield & Wallace 1950, Wright 1951, Fisk 1952, Young & Hudacek 1954), a local disturbance in lipoid metabolism (Atmore et al 1956, Kumon 1969, Hirohara & Morimoto 1971), and an inflammatory process (Jaffe 1964, Aegerter & Kirkpatrick 1968, Byers et al 1968) Infection, however, is accepted as the cause of the disease by most writers, but the aetiological agent is still unknown

The pathological findings in the early stages of the disease consist of a non specific inflammatory reaction of the synovial membrane which becomes oedematous and thickened As the proliferative reaction progresses several cells are found infiltrating the synovium as plasma cells, histiocytes, fibroblastic cells and giant cells Lipid-bearing xanthoid cells and macrophages are also seen The stroma resembles undifferentiated mesenchymal tissue

Macroscopically the synovial membrane is oedematous and hypertrophic, with villus or nodular proliferation and with a brown colour due to pigmentation with haemosiderin

Pigmented villonolular synovitis is a monoarticular condition usually affecting the knee and the phalangeal joints, whereas the hip, elbow, ankle and other joints are rarely involved (Byers et al 1968, Nilsonne & Moberger 1969) Bone lesions in pigmented villonodular synovitis are only occasionally seen in the joints usually affected by the disease They are not uncommon, however, in the rarely involved joints (Jaffe 1960, Chung & Janes 1965) But even in these joints only a few cases

## SUMMARY

A total of 203 profile countings were performed on 68 fractures of the tibial shaft, which included 25 normally healing cases, 37 cases of delayed union, and six cases of non-union. The measurements were performed on the 1st and the 7th day after the injection of strontium. In 27 cases the fracture received 2–3 strontium injections with associated profile counting at different stages of the healing process. The cases of normally healing fractures and delayed union showed differences in the average strontium uptake. However, these differences were not distinct enough to enable classification of individual fractures into groups. In cases requiring bone grafting, the transplant was found to accelerate metabolism and increase the accretion of strontium at the site of the fracture. The investigation shows that the real value of strontium profile counting lies in its ability to give information about the osteogenetic activity of the bone, which is a necessary prerequisite for the healing of the fracture.



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*Key words:* strontium accretion; osteogenetic activity; tibial fracture; normal healing; delayed union; non-union.

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*Figure 5*
*A P radiograph of right hip showing normal joint space and bone cysts at the head of the femur in a patient suffering from pigmented villonodular synovitis*

In this paper seven cases of pigmented villonodular synovitis with bone lesions are presented The purpose of this study is to draw attention to the rare but possible occurrence of bone involvement in pigmented villonodular synovitis in order to avoid misdiagnosis of this condition as other more common joint diseases with similar bone changes The various theories put forward on the pathogenesis of the bone lesions in pigmented villonodular synovitis are mentioned and the radiographical appearance of this condition is described along with the histological picture on which the diagnosis should be established

## MATERIAL

The age range of our seven patients was from 20 to 52 years Four of these were women and three were men The hip joint was affected in four patients (Figures 1 2 3 4) and the knee shoulder and ankle respectively in the three remaining patients (Figures 5 6 7)

The symptoms consisted of progressive pain of long duration at times locking of the joint and stiffness In the case in which the shoulder was involved an enlarged subdeltoid bursa was present while effusion and synovial thickening were found in the knee and ankle joints

*Figure 1 A P and lateral radiographs of left hip with pigmented villonodular synovitis showing bone lesions*

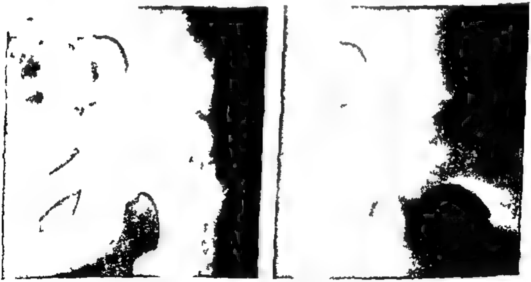

*Figure 2 A P and lateral radiographs of left hip showing bone lesions in a patient suffering from pigmented villonodular synovitis*

have been reported of this condition in association with bone changes (Ghormley & Romness 1954 Breimer & Freiberger 1958 McMaster 1960, Snook 1963 Chung & Janes 1965 Scott 1968 Nilsonne & Moberger 1969 Van Rens 1972)

*Figure 5 A P and lateral X rays of right knee with pigmented villonodular synovitis showing bone cyst at the medial femoral condyle and at the anterior site of the tibial epiphysis*

## RESULTS

The arthrodesed ankle and hip have been painless without any signs of regression for 8 months and 2 years since operation, respectively Two of the remaining three patients, in whom synovectomy and curettage of the bone cysts was performed, are doing well 9 months and 3 years after the operation, respectively The third patient, whose hip joint was operated upon, deteriorated 1 year post operatively with more pain and stiffness of the joint, regression of the bone lesions and collapse of the weightbearing area of the femoral head (Figure 12) In this case a total hip replacement was carried out (Figure 13)

## DISCUSSION

It appears that bone lesions in pigmented villonodular synovitis are not so rare, especially in the joints not commonly affected by the disease

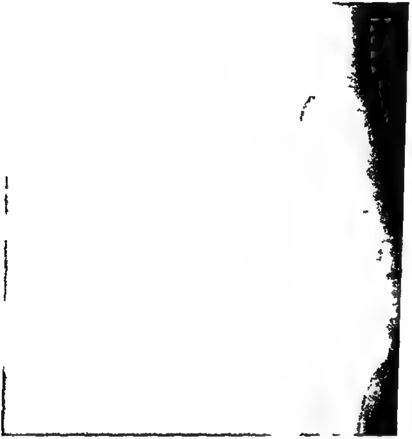

*Figure 4*
*A P radiograph of left hip with bone cysts in the head of the femur in a patient suffering from pigmented villonodular synovitis*

Radiographically the most common finding was bone cysts situated at some distance from the articular surfaces usually well defined but not sclerotic The articular space was preserved and in the late stages of the disease secondary osteoarthritic changes had progressively developed

All the laboratory findings were normal in our patients apart from a raised E S R in the case affecting the shoulder In all seven cases biopsy of the synovium confirmed the diagnosis Histological examination revealed villus hypertrophy of the synovial membrane which indicated active proliferation of the synovial cells and variable fibrosis (Figure 8) Among these stromal cells giant cells lipid bearing xanthoid cells and haemosiderin bearing cells were occasionally seen Haemosiderin was als found extracellularly The synovial membrane was quite vascular (Figure 9) The involved bone showed thinner trabeculae and cysts containing synovial tissue similar to that described above

As regards treatment synovectomy with curettage of the bone cysts was carried out in the knee and two of the hip joints whereas arthrodesis was performed in the case of the third patient with the hip joint affected and in the case with the ankle involved because of the advanced stage of the disease Figures 10 11) In the fourth hip synovectomy has been advised following the biopsy while in the case of the shoulder the subdeltoid bursa was excised because during the synovial biopsy of the joint it was found to be involved in the disease The last two of our patients are awaiting final surgical treatment following their biopsies

Figure 7 Radiographs of right ankle joint with pigmented villonodular synovitis Cystic lesions are mainly seen in the body and neck of the talus

*Figure 6 X rays of left shoulder affected by pigmented villonodular synovitis with bone cysts in the head of the humerus*

such as the hip, ankle, shoulder and others (Ghormley & Romness 1954, Chung & Janes 1965, Breimer & Freiberger 1958, Scott 1968, Nilsonne & Moberger 1969, Van Rens 1972) Being aware of the possible presence of these bone changes in pigmented villonodular synovitis is very helpful in distinguishing this condition from other more common joint diseases with similar bone changes such as osteoarthritis, monoarticular rheumatoid arthritis, and avascular necrosis of the head of the femur in cases where the hip joint is involved This is even more important since the bone changes occurring in pigmented villonodular synovitis can be mistaken for a neoplastic bone or joint lesion such as synovioma There is at least one case of pigmented villonodular synovitis with bone changes reported in the literature which was misdiagnosed as malignant synovioma and hind-quarter amputation was performed (Byers et al 1968) In another reported case of pigmented villonodular synovitis with bone changes affecting the hip joint, the

*Figure 9 Pigmented villonodular synovitis Highly cellular tissue with multinuclear cells*

intra articular pressure This in turn results in small areas of osteoporosis near the joint where the bone cysts are developed The thus formed cysts are finally invaded by the hypertrophic synovium of the joint through fractures of the cystic walls (Chung & Janes 1965) The high intra articular pressure found by other authors as well (Scott 1968) may explain the rare occurrence of the bone cysts in the knee joint which is more usually affected by the disease This is because the articular cavity of the knee is large and can be expanded contrary to joints more rarely involved by the disease, such as the hip, the ankle etc, in which bone changes are a rather common finding

According to McMaster (1960) the cysts are created by the extension of villonodular tissue into the bone through the chondro-osseous area at the articular margin Scott (1968) has found, however, that the invasion of the bone by the hyper trophic synovium takes place through the vascular foramina along with the epiphyseal vessels The villonodular tissue thus invading the bone is further expanded within the bone substance producing the bone cysts by pressure atrophy

*Figure 8 Fragment of villonodular synovitis Villus hypertrophy of the synovial membrane*

synovial proliferation had a retroperitoneal extension simulating an abdominal tumour (Carr et al 1954)

The diagnosis of the condition is based upon the usual clinical signs and the absence of positive laboratory findings but it is mainly made from the radiographical appearance and confirmed by biopsy

The classical X ray findings apart from the soft tissue swelling in the case of involvement of a superficial joint are the bone cysts which are seen at some distance from the articular surface of the affected joint They vary in appearance being usually well defined and non calcified (McMaster 1960 Byers et al 1968 Scott 1968) There is no narrowing of the joint space apart from in the final stages of the disease when segmental necrosis and arthritic changes can be seen (Figure 12)

The characteristic radiographical findings however are the bone cysts described Their pathogenesis is not clear although several theories have been put forward It has been postulated that the extuberant villonodular tissue and the effusion of the joint cause high

*Figure 9 Pigmented villonodular synovitis Highly cellular tissue with multinuclear cells*

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*Figure 10*
*A P radiograph of the case shown in Figure 1 two years after arthrodesis*

Total synovectomy seems to be accepted by most authors as the best treatment for pigmented villonodular synovitis In the presence of bone lesions it should be combined with curettage of the bone cysts, which must be filled by cancellous bone chips when large (Byers et al 1968, Scott 1968) Radiotherapy is also proposed, either as the only treatment (Friedman & Schwartz 1957) or combined with surgery whenever total synovectomy and/or complete curettage of the cysts are inadequate (Scott 1968, Byers et al 1968) Radiotherapy, however, should not be advised as the main treatment for this condition when

*Figure 11 A P and lateral radiographs of the case shown in Figure 7 following arthrodesis*


*Figure 12 A P radiograph of the case shown in Figure 5 one year after synovectomy Note deterioration of the bone lesions and collapse of the weightbearing area of the femoral head*

*Figure 13 A-P radiograph of the case shown in Figures 4 and 12 following total hip arthroplasty*

the bone lesions are extensive, especially in young patients, because of possible stiffness of the joint and because of its carcinogenic effect

Finally, in the case of severe and permanent damage to the joint more radical treatment is advised Arthrodesis or total replacement arthroplasty are the methods of choice depending on the joint affected and the age of the patient (Byers et al 1968, Van Rens 1972)

## SUMMARY

Seven cases of pigmented villonodular synovitis with invasion of the bone are described, four affecting the hip and the remaining three involving the knee, shoulder and ankle joint, respectively The patho-

genesis of the bone changes and the radiographical appearance of the involved joints are described The methods of treatment are discussed

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*Key words* synovitis, villonodular, joints

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Acta orthop scand 46 593–600 1975

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# THE NAIL-PATELLA ELBOW SYNDROME

## *A Case Report*

CARL HENRIK HYBBINETTE

Accepted 23 xii 74

The nail patella elbow syndrome, also called hereditary osteo onycho chondro-dysplasia arthro onycho dysplasia or onycho mesodysplasia is of interest to clinicians and geneticists because of the variety of congenital abnormalities it presents (Brixey & Burke 1950) Many hundreds of cases the majority assembled within a few families have been reported in the international orthopaedic literature but none before in Scandinavia In the patient presented here many of the characteristic deformities were found

## CASE REPORT

The patient is a boy who at 15 years of age was sent to our clinic from a neighbouring orthopaedic hospital At birth he was found to have foot deformities bilateral pes varo adductus which were treated using corrective plasters followed by splints At 6 months of age restricted extension was noticed in both elbows X ray showed nothing pathological A tentative diagnosis of arthrogryphosis multiplex congenita was made on that occasion One year later it was noticed that he had small thumb nails At 5 years of age the absence of both patellae was discovered At 8 years of age an accentuated lumbar lordosis was noticed together with general weakness of the muscles and an eye deformity similar to arcus senilis At 10 years of age a lengthening of the right achilles tendon was performed because of the equinus deformity Proteinuria was accidentally discovered at this age but otherwise the urine was normal. Biochemical findings showed normal serum cholesterol plasma proteins urea clearance and creatinine in serum and normal urine concentration and [illegible]
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On examination we found him to be a slender boy with an accentuated lumbar lordosis Figure 1) A web formation across the cubital fossa was noticed in both elbows as well as an extension defect in the right elbow of 45° and in the left of 35° and restricted supination in the right elbow of 30° and in the left of 20°

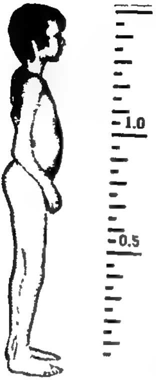


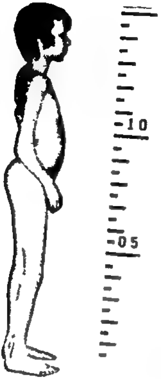

*Figure 1. Cubital web and accentuated lumbar lordosis*

*Figure 2 Right elbow with dislocation of the radius*

*Figure 3 Left knee absence of the patella*

*Figure 4 Iliac horns on both sides*

Marked atrophy of the triceps and biceps as well as the deltoid muscles of both arms was also noticed The circumference of the upper arm was 14 5 cm on both sides compared with the circumference of the webbed elbow which was maximally 22 cm on the right and 24 cm on the left side Radiographs showed bilateral dislocation of the radius together with asymmetrical humeral condyles (Figure 2) Knee deformity was also found There was a moderate genu valgum the left patella was absent and the right was hypoplastic, measuring 2 × 1 cm The tibial tubercles were prominent

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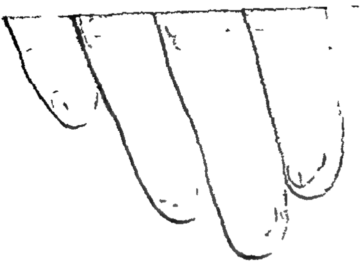


*Figure 7 Right hand with thin nails with triangular lunulae and a central groove*

## DISCUSSION

The first description of this syndrome was given by Chatelain in 1820 and Sedgwick quoted by Little (1897) Turner (1933) gave the first comprehensive report of the syndrome

The syndrome is transmitted as an autosomal dominant trait with a characteristic 100 per cent penetrance Definitive linkage has been established between the nail patella elbow geme locus and that of the AB O blood groups (Jameson et al 1958)

### *Skeletal dysplasias*

*Knee* Absence or hypoplasia of the patella, asymmetrical development of the femoral condyles, sloping tibial plateaux and prominent tibial tubercles osteochondritis dissecans and loose bodies have been reported These abnormalities may cause deformity, instability of the patella genu valgum or walking difficulties (Love & Beiler 1957, Valdueza 1973)

*Elbow* Hypoplasia of the capitulum of the humerus, often with some degree of posterior or anterior dislocation and elongation of the radius, is a special feature The elbow deformities often cause little or no disability and often the patients are unaware of them (Eisenberg 1972, Valdueza 1973)

*Figure 5 The Lester iris*

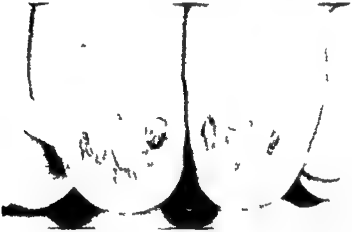
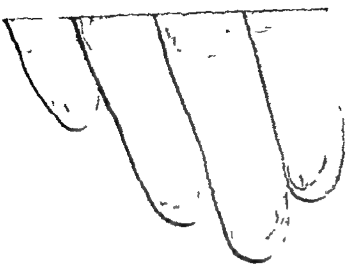


*Figure 6 Both thumbs absence of the ulnar part of the nails*

as were also the medial femoral condyles A very noticeable quadriceps atrophy was found The radiographs showed a hypoplastic laterally displaced patella on the right side and absence of the patella on the left side as well as small lateral femoral condyles (Figure 3) On the pelvis one could easily palpate the pathognomonic iliac horns on both sides The radiographs showed these horns and flaring of the iliac crests (Figure 4) Other deformities found were a shortening of the right leg by 1 5 cm a slight pelvic slope and compensatory scoliosis and also winging of the scapulae The right foot had a slight valgus deformity In both eyes the Lester iris was noticed (Figure 5) The nails of the thumbs showed a characteristic absence of the ulnar half (Figure 6) The other nails exhibited triangular lunulae and were thin with a central groove (Figure 7) The dorsal creases were absent on the distal interphalangeal joints of the second and third fingers on both hands

As the boy had no complaints and lived a perfectly normal life we only registered the deformities and have not planned any corrective operations



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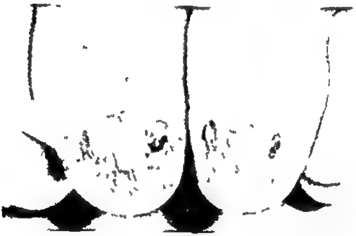

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The severity of the nephropathia is quite variable, it may be serious or it may be harmless (Eisenberg et al 1972)

*Eye deformity*

Heterochromia of the iris was first described by Lester (1936), it is quite common and its relationship to this syndrome is not clear

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*Pelvis* Iliac horns are pathognomonic of the syndrome They are usually symmetrical and well shaped, quite unlike the irregular projections of exostoses and have only been described together with the nail patella-elbow syndrome They may represent a pelvic spinose process, analogous to the spinose and acromial processes of the scapula The horns cause no disability (Darlington & Hawkins 1967) Another pelvic deformity is straightening of the anterior part of the iliac crest or outward flaring of the iliac crest (Turner 1933, Jameson et al 1956)

### *Soft tissue*

Soft tissue changes with web formation around the elbows and axilla have been described as have also flexion contractures of the hip, the knee, the elbow and the fingers Foot deformities equino-varus, calcaneo-valgus and flat feet have been described in association with this syndrome Hypoplasia of the deltoid, triceps and brachio radialis muscles have been reported as well as hypoplasia of the quadriceps or absence of a proper rectus femoris muscle (Love & Beiler 1957, Maini & Mittal 1966, Beals & Eckhardt 1969, Aggarwal & Mittal 1970)

### *Hand*

Laxity of the metacarpal-phalangeal joints or congenital contractures of the interphalangeal joints, mostly in the little fingers, may occur Nail deformities, complete absence or absence of the ulnar half of the nail, or merely a thin grooved nail may occur, this being most marked in the thumb and decreasing in severity in the ulnar direction Triangular lunulae are often seen and absence of the dorsal creases over the distal interphalangeal joints may occur Madelung's deformity and superfluous metacarpal bones have also been described (Montant & Eggerman 1937, Silverman et al 1967)

### *Renal dysplasia*

The nephropathy in this syndrome is classed in the group of chronic nephritis (Whalen & McIntosh 1962) Proteinuria is the cardinal manifestation and casts and blood cells may be present This may be asymptomatic and associated with normal health Impairment of glomerular and tubular function has ben reported (Muth 1965, Norton & Mescon 1968) Renal biopsies have confirmed the non specific glomerular nephritic nature of the lesion in patients with and without proteinuria

The severity of the nephropathia is quite variable, it may be serious or it may be harmless (Eisenberg et al 1972)

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*Key words* nail hypoplasia, patella aplasia, dislocation of caput radii, cubital web, iliac horns, muscular hypoplasia

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Acta orthop scand 46 601–609 1975

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# MONTEGGIA LESIONS AND THEIR COMPLICATING NERVE DAMAGE

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Accepted 10 ii 75

Fracture of the ulnar shaft associated with anterior dislocation of the radial head was first described by Giovanni Battista Monteggia in 1814 (Peltier 1957) Originally the lesion was assumed to be the result of direct trauma but in the light of the works of Evans (1949) and Bado (1962) this view was revised to the effect that in most cases the provoking mechanism is a traumatic torsion of the forearm In children a violent force applied longitudinally to an extended elbow can be the causative factor (Wright 1963 Tompkins 1971) Other more violent and less well defined traumas may result in Monteggia fracture-like lesions all of which have in common dissociation of the proximal ends of the radius and ulna as well as dislocation of the radius in relation to the humerus Bado (1967) classified these lesions into four types under the term Monteggia Lesion so as to give an understanding of the aetiology and a rationale for reduction and bandaging

The present work is concerned with these 4 types of Monteggia lesion

- Type I Fracture of the middle or upper third of the shaft of the ulna and forward dislocation of the upper end of the radius
- Type II Fracture of the middle or upper third of the shaft of the ulna and posterior dislocation of the upper end of the radius
- Type III Fracture of the upper ulnar metaphysis and lateral dislocation of the upper end of the radius
- Type IV Same as Type I associated with fracture of the upper third of the shaft of the radius

Type I is twice as frequent as the Types II and III together whereas Type IV constitutes only 5 per cent of the cases in large series

In addition Bado described different lesions of the elbow and fore

arm as equivalents to the Types I and II Monteggia lesions, in the following they will be referred to as E I and E-II

A Monteggia lesion will often involve the radial nerve which is exposed to injury by this fracture-dislocation on account of the anatomy of the forearm after division of the nerve After having given off the ramus superficialis with motor and cutaneous sensory fibres, the nerve continues in ramus profundus, giving off motor branches to the extensor carpi radialis brevis and supinator muscles The ramus profundus enters the supinator proximal to the point where it passes about the neck of the radius After emerging from the supinator it gives off branches to the extensor digitorum communis, the extensor digiti quinti, the extensor carpi ulnaris, the extensor indices proprius, the abductor pollicis longus, and the extensors pollicis longus and brevis, *and terminates in proprioceptive fibres for the carpal joints* In 25 per cent of all individuals the nerve lies in direct contact with the radius during its passage through the supinator, and in 30 per cent a marked fibrous arch has formed in the muscle insertion by which the nerve is held close to the bone In idiopathic paralysis of the ramus profundus of the radial nerve, exploration often reveals compression of the nerve at this point (Spinner 1972) With both anterior and posterior dislocation of the radius in relation to the humerus the same segment of the nerve is susceptible to injury by traction or compression

## MATERIAL

Over the period 1962–1972 a total of 14 patients with Monteggia lesions were treated four of whom had received their first treatment elsewhere Table 1 shows the characteristics of these patients with regard to sex age and *type of lesion*

The three children had sustained the injuries by falling during play There were two Type I lesions and one Type III One of the Type I lesions had severe dislocation and was associated with total paralysis of the ramus profundus of the radial nerve The two Type I lesions were treated with closed reduction whereas the Type III case required open reduction of the radial head and repair of the ligament Fixation was in plaster of Paris for 6 weeks

The 11 adults had sustained severe and in some cases multiple injuries many of which were more grave than that of the forearm (cf Table 1) Five of the six Type I lesions were treated with osteosynthesis of the ulna One patient had an E I lesion with volar dislocation of the radial head and fracture of the ulnar shaft as well as posterior dislocation of the olecranon This patient had been treated elsewhere with reduction and was not seen in our clinic until 2 months later when he came to have the plaster removed The radial head proved still to be dislocated and there was mal union *of the ulnar fracture resection of the radial head and*

*Table 1 14 Monteggia lesions and their management*

| Patient number | Age, sex and type of lesion | | | Complicating nerve damage | Other associated lesions | Treatment of the Monteggia lesion or equivalent | |
|---|---|---|---|---|---|---|---|
| | | | | | | The ulna | The radius |
| 1 | 10 | F | I | — | – | closed reduction | closed reduction |
| 2 | 66 | F | I-II | — | commotio cerebri | closed reduction | unsuccessful closed reduction (late excision of radial head) |
| 3 | 54 | M | I | — | – | screw | closed reduction |
| 4 | 21 | M | I | + | fractura cruris complicata | rush pin | open reduction |
| 5 | 60 | F | II | — | – | closed reduction | closed reduction |
| 6 | 29 | M | I | — | | rush-pin | open reduction and fascial loop reconstruction |
| 7 | 58 | F | I' II | — | ruptura symphysis<br>luxatio art. sacroiliaca bilat<br>laesio plexus lumbosacralis | closed reduction (late rush pin) | closed reduction (late excision of radial head) |
| 8 | 73 | M | I-I | + | – | closed reduction (late rush-pin) | unsuccessful closed reduction (late excision of radial head) |
| 9 | 52 | F | I' II | — | fractura pelvis comminuta | closed reduction (late screw) | closed reduction (late excision of radial head) |
| 10 | 21 | M | I | + | commotio cerebri | rush-pin | closed reduction |
| 11 | 41 | M | I | + | fractura femoris bilat.<br>fracturae costarum<br>fractura pelvis comminuta | closed reduction | closed reduction |
| 12 | 5 | M | III | — | – | closed reduction | open reduction and repair of ligament |
| 13 | 39 | M | I | + | – | rush pin | closed reduction |
| 14 | 10 | M | I | + | – | closed reduction | closed reduction |

osteosynthesis of the ulna (a m Rush) were carried out Postoperatively, partial radial paresis of the ramus profundus occurred

There was one Type II lesion, which was treated conservatively

E-II lesions occurred in three instances all with dorsal dislocation and avulsion of the radial head together with ulnar fracture, one of these patients also had dorsal dislocation of the olecranon, another had fracture of the olecranon as well as of the distal antebrachium on the same side The three E II lesions were treated initially with closed reduction but the radial head was not repositioned in any of the cases Late extirpation of the radial head was performed in all three, and in two of them osteosynthesis of the ulna as well

Five of the 11 adult patients had radial nerve involvement, and patient No 13 had also partial median nerve involvement

A total of six out of the 14 patients with Monteggia lesions developed radial paresis These six cases all occurred in association with Type I or E I lesions and were confined to the ramus profundus of the radial nerve The diagnosis was based on the clinical examination, only the last two patients underwent neurophysiological examination which confirmed the site of the lesion

Exploration was done in two cases to localize and, if required to treat the lesion Twelve days after early osteosynthesis a small haematoma was noted in patient No 10 at the point of division of the radial nerve, but there was no interruption of continuity or evidence of peripheral degeneration of the nerve Thirty days after early osteosynthesis in patient No 13, discolouration after bleeding was observed at the point where the median nerve gives off the anterior interosseous nerve and at the radial nerve In this case, too the changes were located primarily at the point of division of the radial nerve, there was no interruption of continuity and no fibrosity

## RESULTS

All six patients regained full radial function with the regeneration starting at 6 8 weeks In the 10-year-old boy, however, beginning function was not demonstrable till at 8 weeks

### *Follow-up examination*

All 14 patients were followed up, the mean time of observation was 6 years 1 month (10 years [illegible] months to 8 months) The three children had no after effects, whereas for the 11 adults there were substantial sequelae Nine patients were satisfied with the results and four were fairly satisfied The fourteenth patient was unable to give his opinion as he was demented following a subsequently sustained craniocerebral lesion

Table [illegible] records the loss in range of movement, and the most important radiological findings Unexpectedly, we found two cases of pseudoarthrosis of the ulnar fracture They did not cause much dis-

*Table II Results at follow-up of 14 Monteggia lesions*

| Patient number | Type of lesion | Time of observation in years/months | Loss in ranges of motion as compared with undamaged arm: Flexion | Extension | Pronation | Supination | Radiological findings at follow up |
|---|---|---|---|---|---|---|---|
| 1 | I | 10 years 8 months | none | none | none | none | none |
| 2 | I II | 9 years 8 months | 40° | 5° | none | 40° | 10° angulation of the ulna (radial head removed) |
| 3 | I | 8 years 4 months | 40° | 90° | 50° | 50° | 15° angulation of the ulna severe osteoarthritis of the elbow joint |
| 4 | I | 8 years 7 months | none | none | 25° | none | 10° angulation and non union of the ulna |
| 5 | II | 6 years 8 months | none | 25° | none | 45° | 10° angulation of the ulna severe osteoarthritis of the elbow joint |
| 6 | I | 7 years 6 months | none | none | none | 90° | 15° angulation of the ulna |
| 7 | I II | 6 years | none | none | 25° | 60° | severe osteoarthritis of the elbow joint (radial head removed) |
| 8 | I I | 5 years 3 months | 15° | 30° | 75° | 40° | severe osteoarthritis of the elbow joint (radial head removed) |
| 9 | I II | 5 years 6 months | 60° | 90° | 30° | 75° | radiogram not taken |
| 10 | I | 5 years 4 months | 5° | 10° | none | none | 10° angulation and non union of the ulna |
| 11 | I | 5 years 3 months | 20° | 5° | none | 20° | radiogram not taken |
| 12 | III | 4 years 7 months | none | none | none | none | none |
| 13 | I | 9 months | none | 10° | 20° | none | none |
| 14 | I | 8 months | none | none | none | none | none |

comfort even though on clinical examination it was possible to produce springing and an audible "click" at the site of the fracture Both patients refused *surgical treatment of the pseudarthrosis*, they *had in* the meantime changed to less physically strenuous work but not because of sequelae from the Monteggia lesion Cubitus valgus was present in three patients, in two of them following extirpation of the radial head Patients Nos 3 and 9 had 90° flexion of the elbow, in No 3 movement was restricted to a minimum, and No 9 had arthrodesis

All patients with *radial nerve lesion regained full function* without neurological sequelae In patient No 13 function of the median nerve was not fully restored but continued to improve

## DISCUSSION

The fact that over a 10-year period no more than 14 cases of Monteggia lesions, and of various types at that, were encountered in a large surgical department receiving casualties indicates that these lesions are relatively rare It is, therefore, difficult to acquire personal experience in their management

In children treatment should be conservative although accurate reduction *of the radial head may require surgery to correct* interposition of soft parts The results obtained in the three children in our material confirm that the prospects of complete restoration of function seem to be favourable in this age group (Bryan 1971)

Accurate reduction of the ulna is a precondition for a stable reduction of the head of the radius *In adults osteosynthesis of the ulna* will often be advisable (Naylor 1942, Wenzel & Sander 1969) With regard to the value of suture or plastic reconstruction of the radial annular ligament opinion remains divided (Boyd & Boals 1969, May & Mauck 1961)

In neglected cases, and in equivalent lesions with separation or fracture of the radial head it may be necessary to excise the radial head, this operation should not be done in children, however, until growth of the radius has terminated (Sharrard 1971)

In posterior Monteggia lesion, Pavel et al (1965) obtained poor results as well as complications by early, and no definite *improvement* by late extirpation of the radial head Late extirpation of the radial *head* was done in four of our patients with subsequent improvement of function and reduction of pain, but still the functional results

achieved were among the poorest Cubitus valgus will often result from this procedure

As regards the time of bandaging, 6 weeks for children and 8 weeks for adults will usually be adequate In order to retain the radial luxation, the arm is best fixed at 90° of flexion at the elbow with the forearm rotated in the opposite direction to the movement which provoked the lesion

Development of pseudoarthrosis in the ulnar fracture is a potential risk and the patients should therefore be followed up until sound healing of the fracture has been demonstrated radiologically (Wenzel & Sander 1969) At follow-up two of our patients presented with pseudoarthroses which did not cause much discomfort, however Both were young men who at the time could not be motivated to accept surgical treatment Initially they had been treated with *osteosynthesis of the* ulna (a m Rush) and closed reduction of the radius They had been bandaged for 3 weeks only as it was considered advisable to treat their ramus profundus lesion early and actively (with myotensor, for one thing) A too short time of bandaging in combination with a less stable fixation of the ulnar fracture accounts for the development of pseudoarthroses in both cases

Only the children had no sequelae from the lesion The poorest results were those obtained in the four instances of equivalent lesions and in patient No 3 but none of the remaining six adults ended up entirely without functional restriction Admittedly, our material included several severe cases and some with multiple injuries, but with the rise in traffic and industrial accidents it is to be expected that in future we shall be faced with for one thing, Monteggia lesions of a more severe nature

Spinner et al (1968) described three cases of posterior interosseous paralysis associated with Monteggia fractures in children In two of them function was fully restored after 2 and 14 days respectively, where is in the third it took 7 8 weeks even though regeneration could be demonstrated by electromyography after 5 weeks There are also other reports of peripheral nerve involvement in Monteggia lesions Beddow & Corkery 1960 Smith 1947) Bado's 55 cases included four with radial nerve injury, two with ulnar nerve injury and one with ulnar and median nerve injuries In our material the incidence of ramus profundus affection was particularly high—six cases out of 14, in one of them there was no sign of nerve involvement till after secondary surgery, but in the remaining five it occurred in association

with genuine Type I lesions, of which there were a total of eight The diagnosis was made clinically on the basis of characteristic motor manifestations without concomitant sensory loss

Two of Spinner et al 's cases were transitory with the lesions being of the neuropraxia type In our material the lesions can all be classified as being of the axonotmesis type, as judged from the time that passed before function was regained In no case was there neurotmesis Nor does the literature report so severe cases in connection with Monteggia lesions This fact gives grounds for a conservative, expectant treatment of the neurological complications for up to 8 weeks to allow spontaneous regeneration By electromyographic studies, Spinner et al were able to demonstrate evidence of regeneration after 5 weeks but such studies will often leave the question of the reversibility of nerve damage to the forearm unanswered (Howard 1972)

Although neurotmesis has not been described previously in connection with this type of lesion operative exploration is well indicated if regeneration has not occurred at the expected time

By formation of haematoma with subsequent fibrosis the earlier described anatomy of this region may condition the development of a chronic traumatic entrapment neuropathy requiring surgical decompression to restore function of the nerve (Simeone 1972)

## SUMMARY

Monteggia lesions and their equivalents are reviewed on the basis of the literature and 14 cases encountered over a 10-year period Mention is made of aetiology, classification into types and treatment For the 14 cases in this study the mean follow-up time was 6 years

Likewise, mention is made of the relationship between anatomy and the neuropathy which is a frequent complication in Monteggia lesions In particular the ramus profundus of the radial nerve is exposed to injury but other nerves may also be involved

It is concluded that Monteggia lesions and their equivalents are relatively rare, a fact that may give rise to therapeutic problems In adults the lesions often lead to permanent restriction of movement Patients should be followed up for a long time with a view to early recognition and treatment of ulnar pseudoarthrosis

In case of neurological complications the initial treatment should be conservative and expectant since there is usually no lesion to the nerve in continuity, but if function has failed to return after 8 weeks, surgical exploration is required with decompression in view

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Key words radius injuries ulna injuries radial nerve injuries

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Acta orthop scand 46, 610–620, 1975

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# THE CARPAL TUNNEL SYNDROME

## *A Retrospective Study of 400 Operated Patients*

CARL-HENRIK HYBBINETTE & LENNART MANNERFELT

Accepted 15 ii 75

The carpal tunnel syndrome (CTS) is the most common and the most important of all the entrapment neuropathies of the extremities Space-reducing lesions in the carpal tunnel cause a rise in pressure which provokes symptoms from the pressure-sensitive median nerve The symptoms are referred to as CTS and consist of the triad pain, sensory disturbance and thenar atrophy (Brain et al 1947, Kopell & Thompson 1963)

### *History*

This condition was first described in 1853 by Paget Later Marie & Foix (1913) gave a histological description of the changes in the nerve, intraneural sclerosis and destroyed myelinous fibres and suggested operative treatment which was first carried out by Woltman in 1941 Cannon & Love published in 1946 a series of nine patients who had had surgical treatment The number of articles on this subject has increased during the years but there are only a small number of studies on the late results of relatively large series involving surgical treatment, and the results vary to some extent among these reports Therefore we thought it would be of interest to analyse a fairly large series of operations performed in our clinic

## MATERIAL

During the years 1962–1971 506 cases of carpal tunnel syndrome in 400 patients have been operated upon at the Hand Surgical Unit of the Orthopaedic Clinic in Lund As in other materials (Phalen 1972) there is a predominance of women who comprise more than 70 per cent of the total number of patients (Table 1) The youngest patient was 18 years of age and the oldest 85 The majority, 61 per cent,

were between 41 and 60 years of age (Table 2) Their mean age was 53 years The number of operations have increased over the years

*Table 1 Relationship between sex and operated side in 400 patients with CTS*

| | Right | Right+left | Left | Total |
|---|---|---|---|---|
| Women | 148 | 72 | 62 | 282 |
| Men | 64 | 22 | 32 | 118 |
| Total | 212 | 94 | 94 | 400 |

*Table 2 Sex and age distribution in 400 patients operated for CTS*

| Sex/Age | -20 | 21-30 | 31-40 | 41-50 | 51-60 | 61-70 | 71-80 | 81- | Total |
|---|---|---|---|---|---|---|---|---|---|
| Women | 2 | 21 | 26 | 63 | 104 | 47 | 15 | 4 | 282 |
| Men | – | 4 | 5 | 23 | 43 | 35 | 8 | – | 118 |
| Total | 2 | 25 | 31 | 86 | 147 | 82 | 23 | 4 | 400 |

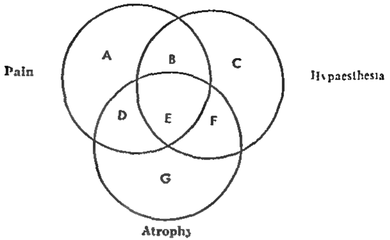
After a review of all the records we sent follow up letters with questionnaires to all patients Enquiries were made regarding pain, decreased sensibility, the condition of the scar, rheumatoid arthritis or other complaints in the hand Nineteen patients had died and 11 could not be traced Thus 30 patients with 41 operated hands were excluded from the material when considering the late results The remaining 370 patients with 465 operated hands had a *mean observation time* of 3 7 years (1-11 years)

## DIAGNOSIS

The diagnosis was established on the basis of both the history and a physical examination

### *Patients history*

The patients complained of paraesthesia often of a *tingling character*, occurring in the *median distribution of the hand The paraesthesia* often started in the third finger and was characteristically nocturnal These symptoms could develop into real pain sometimes radiating proximally into the fore- and upper arm The nocturnal pain awakened the patient, who tried to relieve the symptoms By allowing the hand to drop over the bedside, by shaking the hand or by soaking it in a handbath. During the morning the symptoms usually diminished but they could return during active use of the hand Later, sensation decreased skilled finger movements were lost, weakness of the hand added to the other symptoms and sometimes the patient noticed a wasting of the thumb muscles.




| | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| All 506 operations | 142 | 164 | – | 26 | 167 | 5 | 2 |
| Rheumatoid arthritis, 196 operations | 65 | 59 | – | 14 | 58 | – | – |
| Colles' fracture, 28 patients | 2 | 14 | – | – | 11 | 1 | – |

*Figure 1 Distribution of the various symptoms in 400 CTS patients*

### *Physical examination*

*Pain* The nocturnal pain could be reproduced in the daytime in two ways, either by a venous stasis of the arm (Vainio 1957) or by non forced complete wrist flexion, as described by Phalen (1951) A tourniquet inflated to 100 mmHg around the upper arm was used in the venous stasis test One or both of these methods could usually reproduce or exaggerate the numbness and tingling pain in the median distribution of the hand within 3 minutes most often within 30–60 seconds The test using venous stasis was perform d on 120 arms and was positive in 106 of which 102 were cured by the operation

*Sensation* In 336 hands (66 per cent) there was subjective decreased sensation Hypaesthesia in the median distribution of the hand was tested with touch pin prick and/or two point discrimination In some few cases burns resulted because of the diminished sensation

*Atrophy* Thenar atrophy involving the opponens pollicis and/or the abductor pollicis brevis was noticed in 198 hands (39 per cent) The best way to detect small degrees of thenar atrophy was to observe the thenar eminence in profile

*Weakness* Occasionally only decreased strength in these muscles was observed measured against breaking force with an Intrinsicmeter (Mannerfelt 1966) Some patients could not oppose the thumb

*Combination of symptoms* Almost one third of all the operated cases had only pain hypaesthesia and were more cases with the cases with carpal tunnel syndrome resulting after a Colles fracture only a minority had pain alone and most of the patients had pain hypaesthesia and often also atrophy (Figure 1)

*Duration of symptoms* The duration of symptoms in 318 out of 506 cases varied

Slightly less than three quarters had had symptoms for less than 2 years, but five patients had had symptoms for more than 20 years. No certain correlation between the duration and the combination of the symptoms could be shown.

*Electrodiagnosis.* Electrodiagnostic determination of the conduction time for the sensory and the motor fibres of the median nerve and electromyographic studies were used in 199 patients, often when there was diagnostic uncertainty. In 180 of these patients the results revealed a carpal tunnel syndrome. In 19 patients with 22 operated hands these investigations were normal, but other objective signs made a diagnosis of carpal tunnel syndrome probable and 18 of the 22 operated hands were cured after the operation. Thirteen of these 22 hands had pain only, seven had hypaesthesia and two had atrophy.

*Earlier diagnosis*

Cervical rhizopathy may have some similarities with the carpal tunnel syndrome (Campbell 1962). [illegible] of the 400 patients had been treated earlier for rhizopathy, often over many years, the longest being 30 years. 75 of these [illegible] patients were completely pain free in their hands after operation for CTS, thus excluding a diagnosis of rhizopathy. Some few hands with oedema had been diagnosed as Dupuytren's contracture.

*Table 5. The different conditions producing CTS in 400 patients*

| Condition | No. of patients | | | No. of hands |
|---|---|---|---|---|
| | Women | Men | Total | |
| Tenosynovitis in rheumatoid arthritis | 106 | 45 | 151 | 196 |
| Tenosynovitis, non specific chronic or fibrosis | 104 | 34 | 138 | 170 |
| Fractura radii (Colles' fracture) | 22 | 6 | 28 | 32 |
| Carpal arthrosis, pseudarthrosis of scaphoideum | 2 | 11 | 13 | 13 |
| Torsion or blunt trauma | 4 | 7 | 11 | 12 |
| Diabetes mellitus | 8 | 3 | 11 | 17 |
| Thyroid diseases | 8 | – | 8 | 9 |
| Pregnancy | 7 | – | 7 | 8 |
| Contraceptive pill | 9 | – | 9 | 15 |
| Ganglion | 3 | 4 | 7 | 7 |
| Muscle bellies in the carpal tunnel | – | 3 | 3 | 3 |
| Lipoma in the carpal tunnel | 1 | – | 1 | 1 |

*Pathology*

Tenosynovitis of the flexor tendons combined with rheumatoid arthritis was the most common cause of the syndrome, occurring in almost 30 per cent of the patients. Thickening of the flexor *synovialis* was an almost regular finding at operation. Of the 506 cases treated surgically 112 had biopsy specimens taken of the flexor synovialis. The pathologists *reported* that 23 of these were rheumatoid arthritis reported above, and the rest were dominated by those with a chronic non specific inflammation; many had fibrosis of the *synovialis* or oedema and in

*Figure 2 Incision used for splitting the transverse carpal ligament*

a minority there were no pathologic changes In some patients various systemic factors diabetes mellitus or myxoedema may have contributed to the syndrome almost always combined with thickening of the synovialis Retention of water during pregnancy or when taking contraceptive pills was sometimes a cause of the syndrome Fractures and other injuries about the wrist could be causative factors In the traumatic group women dominated in the patients with Colles fracture and men in the patients with carpal arthrosis caused by previous fractures mostly of the scaphoid bone Rare causes of increase in the volume of the contents of the carpal tunnel were ganglions, lipomas and abnormal muscle bellies in the tunnel In some patients nothing abnormal was found at operation (Table 3)

## TREATMENT

### *Medical treatment*

Not every patient with CTS needs surgical treatment (Mumenthaler 1964) Splinting of the wrist analgetics diuretics antiflogistics or injections of steroids into the carpal tunnel can help but not very often and especially not when the symptoms have been present for a long period of time (Vaughan-Jackson 1966)

### *Surgical treatment*

Operations were performed on patients with pains which were severe or of long duration and on patients with decreased sensation or thenar atrophy However in pregnancy we often waited for possible recovery after delivery (Wilkinson 1960)

All the operations were carried out in a bloodless field and either under brachial plexus block or general anaesthesia Seventeen surgeons performed the operations one (Mannerfelt) carried out 211 operations eight surgeons performed 26–43 operations each and the rest fewer than eight operations The same operative technique has been used by all surgeons over the last 8 years We used a curved incision following the thenar base (Figure 2) to expose the transverse carpal ligament which was divided at its ulnar border A small strip of it was resected The

distal part of the tendon of m palmaris longus was resected Neurolysis of the thenar motor branch was always performed Various anatomical anomalies were found during this manoeuvre reported earlier by Mannerfelt & Hybbinette (1972) The bottom of the carpal tunnel was inspected to exclude tumours ganglions or bony spurs (Brooks 1952 Mannerfelt & Norman 1969 Inglis et al 1972) Teno synovectomy was carried out when we found pronounced thickening of the flexor synovialis Exact suture of the skin with an atraumatic technique was followed by immobilization of the wrist in a splint for about 10 days

Very often a compression of the median nerve was observed under the ligament and in 185 cases a pseudoneuroma proximal to the compression was reported In 34 cases no compression was observed but 29 of these cases became pain free

*Postoperative care* The hand was kept elevated for 24 hours. A sling was avoided to prevent swelling of the hand Early active finger flexion and extension were of the utmost importance in patients with rheumatoid arthritis or marked teno synovitis in order to prevent postoperative adhesions of the flexor tendons

## RESULTS

### Early results

The relief of pain was often dramatic The patient noticed a great amelioration of the symptoms and had an undisturbed night's rest which had not been possible for a long time Total or almost total relief from the pain was reported in 455 of the 506 operated cases soon after the operation The majority of the not completely successful cases had minor paraesthesias which were of more than 3 months post-operative duration Many patients were relieved from the CTS but experienced discomfort caused by other diseases viz, 12 cases of rheumatoid arthritis eight cases of cervical rhizopathy, seven cases of diabetic polyneuropathy, six cases of idiopathic polyneuropathy, one patient with intraneural posttraumatic fibrosis and one with pain after Colles fracture

### Long term results

*Pain* The patients who replied that they did have pain were examined in all cases except two who did not wish to participate in the follow up

In the late examination among the 370 patients with 465 operations seven patients had pain which could be attributed to a median nerve irritation in the carpal tunnel

Pain of another origin was found in 40 patients with 46 operated hands Of these patients, 17 had rheumatoid arthritis, 12 cervical rhizopathy and five discomfort after a fracture No significant differ-

*Figure 2 Incision used for splitting the transverse carpal ligament*

a minority there were no pathologic changes In some patients various systemic factors, diabetes mellitus or myxoedema, may have contributed to the syndrome almost always combined with thickening of the synovialis Retention of water during pregnancy or when taking contraceptive pills was sometimes a cause of the syndrome Fractures and other injuries about the wrist could be causative factors In the traumatic group women dominated in the patients with Colles' fracture and men in the patients with carpal arthrosis caused by previous fractures mostly of the scaphoid bone Rare causes of increase in the volume of the contents of the carpal tunnel were ganglions, lipomas and abnormal muscle bellies in the tunnel In some patients nothing abnormal was found at operation (Table 3)

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*Complications*

Two patients operated in the first years with a transverse incision sustained an injury to the sensory palmar branch and one to the thenar branch of the median nerve Eight patients considered the scar to be ugly, six of these developed keloid in the scar and were operated with excision of the scar Three patients developed a shoulder hand-finger syndrome postoperatively

*Carpal tunnel syndrome associated with some other conditions*

*Rheumatoid arthritis* In our material this was a common cause of CTS These patients often had pain as a result of tenosynovitis and arthritis in the hand but a careful investigation often revealed the CTS as also mentioned by Barnes & Currey (1967) Bilateral operation was rather common, 42 patients out of 151, compared with 54 out of 240 non rheumatoid patients Fifteen patients (in whom CTS was the initial symptom) developed rheumatoid arthritis after the operation

*Colles' fracture* The syndrome could start immediately after the accident (though this could not be verified) or after some time because of malposition, abundant callus, oedema, intra articular exudate or haematoma (Abbot & Saunders 1933, Kinley & Evarts 1968, Frykman 1967) There could be a regression of the symptoms when the patient used the hand and one therefore waited 1–2 months before operating 28 patients with Colles fracture were operated The results were good in 21 four in three and the rest did not have CTS but symptoms related to the fracture

*Peripheral neuropathies* When the nerve was involved in a peripheral neuropathy, here most often diabetes mellitus, it was more susceptible to the various causes of carpal tunnel syndrome There were 11 patients with diabetes mellitus three of the women also had rheumatoid arthritis and two of the men some trauma as an additional factor The postoperative period was often protracted before they became pain free, and one of the poorest results was in a diabetic operated bilaterally twice, the poor result being due to the polyneuropathy

*Mistakes*

Eight of the patients were not helped at all and are considered as being wrongly diagnosed The true diagnosis was cervical rhizopathy in four, neurosarcoma of the brachial plexus in one, syringomyelia in one,

ences in results between the operations performed by the different surgeons could be found. 98 per cent of the patients were thus relieved from the pain caused by a carpal tunnel syndrome. The age of the patient or duration of the symptoms did not seem to influence the result.

*Sensation.* The return of normal sensation was usually slower than the regression of the pain. In the late examination group 256 patients with 311 operations had hypaesthesia preoperatively. It was found that 24 patients with 27 operated hands still had hypaesthesia because of nerve affection in the carpal tunnel. Of these, nine cases were more pronounced and the rest only slightly with a small decrease in sensation at most, often at the top of the third finger. Ninety per cent of the patients with hypaesthesia were thus relieved after the operation.

*Atrophy.* The general impression was that the thenar atrophy usually regressed although it sometimes tended to be permanent. This aspect was not examined systematically in this work but is now being studied in a prospective study at the clinic.

## *Reoperations*

It was necessary to re-explore 18 hands in 17 patients because of pain. One of these patients was reoperated last year and is thus not included in the 10-year survey. In four cases it was found that the distal part of the transverse carpal ligament was still intact. In other cases we found fibrous proliferation and adhesions within the carpal tunnel and/or hypertrophied tenosynovitis of the flexor tendons, as did also Langloh & Linscheid (1972). An epineurectomy was performed in only one patient, reoperated last year.

The patients with incomplete sectioning of the transverse carpal ligament had incomplete or no relief after the first operation and were reoperated after a mean period of time of 5 months (range 1–9). The patients with tenosynovitis or fibrous proliferation usually obtained relief after the first operation but later the carpal tunnel syndrome returned and they were reoperated after an average period of 19 months (range 4–48).

The mean observation time of these 18 reoperations was 3.4 years, ranging from 10 months to 7 years.

The results of the reoperations with regard to pain were good in 10 hands, fair (improved condition) in seven and poor in one (with an intraneural fibrosis following a severe compression trauma).

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post-radiologic damage of the brachial plexus in a women with malignancy of the breast, and one aneurysm of the subclavian artery.

## DISCUSSION

This series with 506 operations in 400 patients over a period of 10 years is one of the largest reported in the literature. Phalen (1972) reported on 235 operated wrists, Yamaguchi et al. (1965) 459 cases, Czeuz et al. (1966) 430 operated patients and from Europe Semple & Cargill (1969) 150 operated patients. From Scandinavia, Rasmussen & Stougård (1969) reported on 78 patients and Rietz & Önne (1967) on 65 patients.

This series differs somewhat from the others in that rheumatoid arthritis was an important actiological factor, accounting for 151 of the 400 operated patients. One specific factor mentioned previously is the contraceptive pill. In this series 49 women were less than 40 years of age, and of these nine used the pill and had no other possible cause of the syndrome. There have also been many more young women with this combination of the carpal tunnel syndrome and the pill, but where there was no indication for surgery.

The duration of the symptoms, the age of and the distribution of the patients are about the same as in other reports, such as Phalen's (1972).

The test with venous stasis has proved very valuable in establishing the diagnosis and we think it is as good as the wrist flexion test. Like Tanzer (1959), we consider the tourniquet test described by Gilliatt & Wilson (1953), provoking ischaemia of the hand, to be uncertain.

The majority of the patients had disabling symptoms with pain and decreasing sensation. Operation was not carried out on patients with only vague symptoms, although none of our patients became worse after the operation. In a similar manner to Lipscomb (1959) and Lichtman et al. (1968) operative treatment was not restricted.

The transverse carpal ligament should be divided under direct vision. Blind splitting of the ligament is not recommended because it is often not complete and because it makes inspection of the carpal tunnel impossible. Neurolysis of the thenar motor branch is necessary, at least in the patients with atrophy. We do not think that internal neurolysis as suggested by Curtis & Eversman (1973) is necessary as a routine operation, at least not at the first operation. Like Phalen (1972) we think that it may be dangerous because even minor trauma may result in painful causalgia.

The result of the operation is mostly very good considering relief of

the pain and amelioration of the hypaesthesia Many cases with thenar atrophy will regenerate postoperatively Our findings do not agree with those of Semple & Cargill (1969), who reported failure in 25 per cent of the patients perhaps because of irreversible neuropathy We agree with Phalen (1966) and Rietz & Önne (1967) that it is a rewarding and successful operation

## SUMMARY

Carpal tunnel syndrome is a common cause of pain, often combined with hypaesthesia in the median distribution of the hand and atrophy of the thenar We describe pre-, per-, and post-operative findings in 400 patients Venous stasis is a good diagnostic method in establishing the syndrome Operative treatment generally gives freedom from pain and normalization of sensibility

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*Key words* median nerve compression aetiology diagnostic findings operative treatment short and long term results

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# DEVELOPMENT OF OSTEOPENIA IN THE FOURTH LUMBAR VERTEBRA DURING PROLONGED BED REST AFTER OPERATION FOR SCOLIOSIS

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Accepted 23 1 75

Photon absorptiometry has proved to be a very accurate method for the determination of bone content (Cameron & Sorensen 1963) The wasting of skeletal mass during prolonged bed rest has so far been investigated in metabolic studies and by photon absorptiometry of peripheral skeletal parts such as calcaneus and the distal forearm (Deitrick et al 1948 Rose 1966 Goldsmith et al 1969 Donaldson et al 1970 Vogel & Friedman 1970, Hulley et al 1971, Hantman et al 1973) These studies have been carried out on males Females whose "physiological" loss of bone begins at an earlier age and proceeds at a more rapid rate are probably more susceptible to immobilization in bed partly because their ability to regain lost bone is more doubtful (Harris & Heaney 1969 Nilsson & Westlin 1975)

The aim of this study was to follow the effect of prolonged bed rest on the bone mineral content of the fourth lumbar vertebra in a group of young females strictly immobilized in bed after operations for scoliosis

## MATERIAL

Thirteen females 13–[illegible] years old all with idiopathic scoliotic deformities of the spine were studied Subjects with any other disease which could interfere with bone metabolism were excluded. Preoperatively all had normal values for Ca/serum P serum, Ca urine and P urine All were operated upon with correction according to the method of Harrington and posterior spinal fusion Only patients with fusions above the fourth lumbar vertebra were included (Tables 1 and 2)

Seven of the patients group A were operated upon in two stages with an interval of fourteen days At the first operation the Harrington rod was inserted on the concave side and the curvature corrected At the second operation further correction and fusion were performed (Nordwall 1973) Six patients group B were

*Table 1 Data and results Group A patients*

| Patient | Age (years) | Brace before operation (months) | Rod span and fusion length | Iliac apophysis (0–5) | Immobil in bed (weeks) | Initial bone content of $L_4$ | Bone content after immobil $L_4$ | Bone content change (%) | Weekly change of bone content (%) |
|---|---|---|---|---|---|---|---|---|---|
| MK | 15 | 15 | Th4–L2 | 5 | 6.0 | 11.54 | 10.05 | −12.88 | −2.15 |
| AR | 13 | 0 | Th5–L1 | 4 | 5.6 | 11.76 | 8.60 | −26.84 | −4.82 |
| IJ | 16 | 0 | Th6–L2 | 5 | 5.9 | 11.36 | 10.04 | −11.67 | −1.99 |
| MS | 16 | 0 | Th2–Th11 | 5 | 5.6 | 9.09 | 8.09 | −11.05 | −1.98 |
| MH | 16 | 0 | Th4–L2 | 5 | 6.6 | 12.56 | 11.23 | −10.60 | −1.61 |
| BA | 16 | 24 | Th6 L3 | 5 | 6.3 | 8.41 | 7.63 | −9.24 | −1.47 |
| ML | 15 | 0 | Th6–L2 | 5 | 5.4 | 12.30 | 9.29 | −24.76 | −4.57 |

*Table 2 Data and results Group B patients*

| Patient | Age (years) | Brace before operation (months) | Rod span and fusion length | Iliac apophysis (0–5) | Immobil in bed (weeks) | Initial bone content of $L_4$ | Bone content after immobil $L_4$ | Bone content change (%) | Weekly change of bone content (%) |
|---|---|---|---|---|---|---|---|---|---|
| AH | 17 | 36 | Th6–L2 | 5 | 3.4 | 12.26 | 11.45 | −7.3 | −2.17 |
| AK | 16 | 0 | Th5–L1 | 5 | 4.3 | 11.62 | 11.47 | −1.3 | −0.28 |
| BL | 15 | 0 | Th5–L1 | 4 | 3.0 | 9.72 | 9.34 | −1.0 | −1.33 |
| LO | 14 | 0 | Th6–L1 | 0–1 | 3.3 | 8.82 | 8.16 | −7.5 | −2.24 |
| HF | 18 | [illegible] | Th5–L2 | 5 | 4.0 | 10.61 | 9.84 | −7.2 | −1.[illegible] |
| IP | 17 | 37 | Th6–L1 | 5 | 3.1 | 9.63 | 10.01 | +4.0 | +1.26 |

operated upon in the same way but with correction and fusion performed during the same operation

After the operation(s) the patients were strictly immobilized in bed in recumbency usually supine In both groups during the first five days movements of the trunk in bed were permitted only with the full assistance of the nursing staff Later on the patients were permitted after instruction to roll themselves to either side No external support was used until the patients were allowed to get out of bed two (group B) to four (group A) weeks following the first or second operation respectively

The detailed postoperative mobilization program has been described earlier and is aimed to avoid as much as possible any strain on the back (Nachemson & Elfstrom 1973)

## METHODS

Dual photon absorptiometry involves the use of two radionuclides which emit gamma radiation with different energies ($^{241}$Am with 59.6 keV and $^{137}$Cs with 662 keV) The radiation sources are so arranged that their gamma radiation passes through the object to be measured in a common collimated radiation beam (Figure 1) The transmitted gamma radiation is registered digitally with a scintillation detector—*both energies* simultaneously The patient lies on a couch which is moved in the transversal direction and an electronic control unit enables intermittent scanning in steps of 4 mm Transmission measurements are performed during preselected time intervals between the steps

Both photon energies are exponentially attenuated by the object the higher energy mainly by the Compton effect the lower by both the Compton and photoelectric effects In materials with higher atomic number than soft tissue e g bone mineral the photoelectric effect will dominate in the attenuation of the lower energy This means that the lower energy will be relatively more attenuated than the higher when it passes a region containing bone Application of the law of exponential attenuation to the case of the two energies will then give the bone mineral content in the units g cm$^{-2}$ denoted $m_B$ The amount of lean soft tissue can be eliminated mathematically The existence of adipose tissue in the path of the beam will, however introduce an error The common scanning technique (Cameron & Sorensen 1963) and our method too partly eliminate this error by measuring along a transverse path across the bone continuously or intermittently Plotting $m_B$ versus the position x gives a so-called bone profile curve (Figure 2) Points outside the bone on both sides are selected to form end points of a baseline above which the bone profile curve is integrated yielding the bone mineral content in the units g cm$^{-1}$ This procedure gives a true correction if the adipose tissue is constant or varying linearly along the measurement path

This is not quite true in our case because the vertebra contains relatively large amounts of fatlike tissue It is not possible to correct for this with the present method but it is assumed that the error is constant when measuring the same vertebra in the same patient several times The reproducibility should thus be unaffected by this source of error A more detailed description of the theory and experimental technique has been presented elsewhere (Roos & Sköldborn 1974)

*Table 1 Data and results Group A patients*

| Patient | Age (years) | Brace before operation (months) | Rod span and fusion length | Iliac apophysis (0–5) | Immobil in bed (weeks) | Initial bone content of $L_4$ | Bone content after immobil $L_4$ | Bone content change (%) | Weekly change of bone content (%) |
|---|---|---|---|---|---|---|---|---|---|
| MK | 15 | 15 | Th4–L2 | 5 | 6 0 | 11 54 | 10 05 | −12 88 | −2 15 |
| AR | 13 | 0 | Th5–L1 | 4 | 5 6 | 11 76 | 8 60 | −23 84 | −4 82 |
| IJ | 16 | 0 | Th6–L2 | 5 | 5 9 | 11 36 | 10 04 | −11 67 | −1 99 |
| MS | 16 | 0 | Th2–Th11 | 5 | 5 6 | 9 09 | 8 09 | −11 05 | −1 98 |
| MH | 16 | 0 | Th4–L2 | 5 | 6 6 | 12 56 | 11 23 | −10 60 | −1 61 |
| BA | 16 | 24 | Th6–1 3 | 5 | 6 3 | 8 41 | 7 63 | − 9 24 | −1 47 |
| ML | 15 | 0 | Th6–1 2 | 5 | 5 4 | 12 30 | 9 29 | −24 76 | −4 57 |

*Table 2 Data and results Group B patients*

| Patient | Age (years) | Brace before operation (months) | Rod span and fusion length | Iliac apophysis (0–5) | Immobil in bed (weeks) | Initial bone content of $L_4$ | Bone content after immobil $L_4$ | Bone content change (%) | Weekly change of bone content (%) |
|---|---|---|---|---|---|---|---|---|---|
| AH | 17 | 36 | Th6–L2 | 5 | 3 4 | 12 26 | 11 45 | −7 3 | −2 17 |
| AK | 16 | 0 | Th5–L1 | 5 | 4 3 | 11 62 | 11 47 | −1 3 | −0 28 |
| BL | 15 | 0 | Th5–L1 | 4 | 3 0 | 9 72 | 9 34 | −4 0 | −1 33 |
| LO | 14 | 0 | Th6–1 1 | 0–1 | 3 3 | 8 82 | 8 16 | −7 5 | −2 24 |
| HI | 18 | 60 | Th5–1 2 | 5 | 4 0 | 10 61 | 9 84 | −7 2 | −1 62 |
| LF | 17 | 37 | Th6–L1 | 5 | 3 1 | 9 63 | 10 01 | +4 0 | +1 26 |

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*Table 1 Data and results Group A patients*

| Patient | Age (years) | Brace before operation (months) | Rod span and fusion length | Iliac apophysis (0–5) | Immobil in bed (weeks) | Initial bone content of $L_4$ | Bone content after immobil $L_4$ | Bone content change (%) | Weekly change of bone content (%) |
|---|---|---|---|---|---|---|---|---|---|
| MK | 15 | 15 | Th4 L2 | 5 | 6 0 | 11 54 | 10 05 | −12 88 | −2 15 |
| AR | 13 | 0 | Th5–L1 | 4 | 5 6 | 11 76 | 8 60 | −23 84 | −4 82 |
| IJ | 16 | 0 | Th6–L2 | 5 | 5 9 | 11 36 | 10 04 | −11 67 | −1 99 |
| MS | 16 | 0 | Th2–Th11 | 5 | 5 6 | 9 09 | 8 09 | −11 05 | −1 98 |
| MH | 16 | 0 | Th4–L2 | 5 | 6 6 | 12 56 | 11 23 | −10 60 | −1 61 |
| BA | 16 | 24 | Th6–L3 | 5 | 6 3 | 8 41 | 7 63 | − 9 24 | −1 47 |
| ML | 15 | 0 | Th6–L2 | 5 | 5 4 | 12 30 | 9 29 | −24 76 | −4 57 |

*Table 2 Data and results Group B patients*

| Patient | Age (years) | Brace before operation (months) | Rod span and fusion length | Iliac apophysis (0–5) | Immobil in bed (weeks) | Initial bone content of $L_4$ | Bone content after immobil $L_4$ | Bone content change (%) | Weekly change of bone content (%) |
|---|---|---|---|---|---|---|---|---|---|
| AH | 17 | 36 | Th6–L2 | 5 | 3 4 | 12 26 | 11 45 | −7 3 | −2 17 |
| AK | 16 | 0 | Th5–L1 | 5 | 4 3 | 11 62 | 11 47 | −1 3 | −0 28 |
| BL | 15 | 0 | Th5–L1 | 4 | 3 0 | 9 72 | 9 34 | −4 0 | −1 33 |
| LO | 14 | 0 | Th6 L1 | 0–1 | 3 3 | 8 82 | 8 16 | −7 5 | −2 24 |
| HF | 18 | 60 | Th5–L2 | 5 | 4 0 | 10 61 | 9 84 | −7 2 | −1 62 |
| LF | 17 | 37 | Thf L1 | 5 | 3 1 | 9 63 | 10 01 | +4 0 | +1 26 |

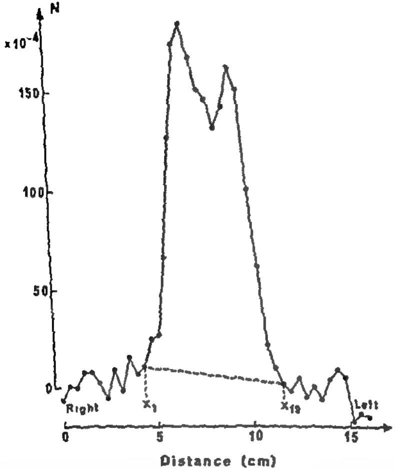


*Figure 2 Bone profile curve showing bone content (N) as a function of measuring position for a normal subject N is proportional to* $m_B$

e g adjustment variations or movements of the subject *during the* measurement. The combined error, the reproducibility, has been experimentally estimated by measuring four normal subjects *ten times each* and calculating the standard deviation of the results for each individual The coefficient of variation varied in the range from 3 4 per cent to 5 7 per cent The *reproducibility* of the method is thus considered to be better than 6 per cent (Roos & Sköldborn 1974)

*Method of patient measurement*

The patient lies in the supine position *on the* couch with flexed knees and hips A special cushion placed under the knees provides the stability *and the* same angle

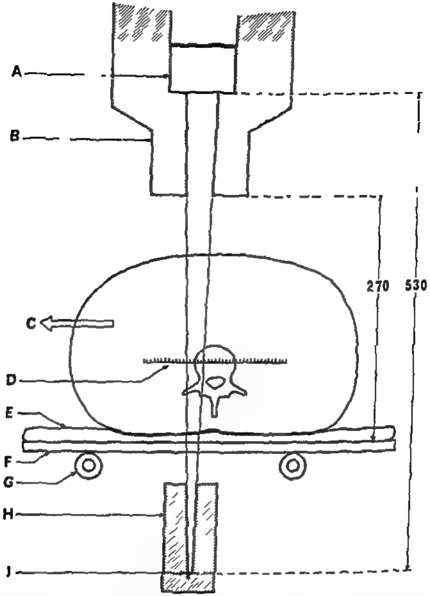


*Figure 1 Diagram showing measurement procedure A = scintillation crystal B = lead collimator for the detector C = patient's direction of movement, D = scale for demonstrating the successive measuring positions, E = polythene mattress F = couch G = ball bearing H — container for the sources with collimation of emitted radiation beam I = radiation sources Distances are stated in mm*

*Precision*

The main cause of variation is the random nature of radioactive decay— the number of counts will vary according to the Poisson distribution This variation will normally cause a coefficient of variation of about 3 per cent in the measurement result Other variations may be attributed to the particular subject They include all factors which cannot be reproduced exactly from one measurement to another,

reproducibility or, less probably, be a quite unexpected reaction to immobilization Monthly loss in group B was 6 12 per cent with LE excluded and 4.24 per cent with LE included

## DISCUSSION

Prolonged bed rest as well as other kinds of immobilization result in disuse osteopenia The absence of mechanical stresses upon the skeleton produces among other things a negative calcium and phosphorus balance and a decline in bone density, primarily because of an exaggerated bone resorption (Heaney 1962, Harris & Heaney 1969).

It is well known that osteoclasts, when resorbing bone, operate from a free surface Consequently, cancellous bone with its high surface-to-bone volume ratio is lost faster with ageing and disease than cortical bone (Frost 1966) It also appears that the atrophy of the skeleton begins and is always more marked in the vertebrae than in the extremities (Frost 1966)

Metabolic studies have revealed a monthly loss of about 0 5 per cent of total body calcium during prolonged bed rest (Deitrick et al 1948, Donaldson et al 1970, Goldsmith et al 1969, Hantman et al 1973, Hulley et al 1971, Issekutz et al 1966) Immobilization in bed after spinal fusion, although not studied in a strict metabolic way, produced just about the same urinary losses of calcium (Millard et al 1970) Photon absorptiometry has shown a loss of bone content in calcaneus at a much higher rate than in the distal forearm and even at a tenfold higher rate than compared to the total losses of body calcium (Hantman et al 1973, Hulley et al 1971, Vogel & Friedman 1970, and others)

The young women in this study showed a wide individual variation in bone content of the fourth lumbar vertebra already at the first scanning irrespective of whether they had used Milwaukee braces before operation or not As pointed out by others the great biological variation makes longitudinal studies of changes in bone content more valuable than cross sectional studies (Dalén 1973)

The wide range of bone loss from the fourth lumbar vertebra suggests a rather individual susceptibility to immobilization The highest rate of bone loss, in patient AR about 4 8 per cent weekly, was at an almost fourfold higher rate than previously seen in the calcaneus

This study shows that, at least in this group of patients, during bed rest the loss of bone content in the lumbar spine is more extensive than in other investigated bones However, it should be taken into account

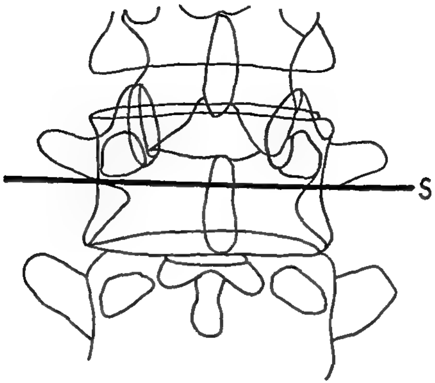


*Figure 3 Posterior view of $L_4$ with the scanning path S*

in the lumbar spine from one scanning to another The fourth lumbar vertebra (the fourth free vertebra without any rib counted from cranial to caudal in the lumbar spine) is localized with an X ray tube and image intensifier attached to the detector stand The centre of the scanning track is placed at about 5 mm from the most cranial point of the projection of the spinous process of the vertebra (Figure 3)

## FINDINGS

In group A (Table 1) all patients had had their menarche more than half a year prior to operation All were near completion of bone maturity according to the iliac apophysis sign (Risser 1948) and their mean skeletal age (according to Gruelich & Pyle) was 15 5 years

In group B (Table 2) all except LO had started to menstruate more half a year prior to operation Mean skeletal age in this group was 16 years LO was the only one who had more than 2 years left before reaching skeletal maturity

In group A the weekly rate of bone mineral loss varied between 4 82 and 1 47 per cent Mean monthly loss was 10 7 per cent in this group In group B the weekly loss varied from 2 24 to 0 28 per cent LE was an exception, showing a gain of bone content This can reflect the error in

reproducibility or, less probably, be a quite unexpected reaction to immobilization Monthly loss in group B was 6 12 per cent with LE excluded and 4.24 per cent with LE included

## DISCUSSION

Prolonged bed rest as well as other kinds of immobilization result in disuse osteopenia The absence of mechanical stresses upon the skeleton produces among other things a negative calcium and phosphorus balance and a decline in bone density, primarily because of an exaggerated bone resorption (Heaney 1962, Harris & Heaney 1969)

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This study shows that, at least in this group of patients during bed rest the loss of bone content in the lumbar spine is more extensive than in other investigated bones However, it should be taken into account

that the patients in this study were also subjected to a major surgical procedure involving bone tissue

It has previously been demonstrated that after fracture the loss of bone mineral content is not confined to the injured bone only but also occurs in adjacent bones (Bauer & Carlsson 1955) Even if the lowest point of the fusion in twelve of the patients was two or more vertebrae above $L_4$ some part of the total bone loss might be of a post traumatic type

Children restitute their bone losses, at least after disuse osteopenia caused by immobilization after fractures (Nilsson & Westlin 1971) Young males and grown-up men restitute, at least to some extent, their bone losses, with known exceptions (Hantman et al 1973, Hulley et al 1971, Nilsson 1966) Women with immobilization after Colles' fracture show a tendency to normalize their bone density at about two years after the fracture episode (Nilsson & Westlin 1975)

Preliminary results from a parallel study of women with patholog ical osteoporosis reveal that at least four of the young women in this study have a bone content after immobilization in bed lower than that of some of the women with collapsed vertebrae

Future measurements of the patients in the present study will reveal if the restitution of their vertebral mineral loss follows the pattern earlier seen in men and in other bones

## SUMMARY

The fourth lumbar vertebra was studied with dual photon absorptiometry in a group of young women immobilized in bed for 21 to 46 days after operation for scoliosis Twelve out of 13 showed loss of bone content The monthly loss in most patients highly exceeded earlier reported losses from other bones and significantly exceeded the methodological error

## ACKNOWLEDGEMENT

This investigation has received financial support from the Swedish Medical Research Council and Greta and Einar Askers Fund

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*Key words* : osteoporosis, scoliosis, absorptiometry bone mineral content immobilization, lumbar vertebrae

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# THE EFFECT OF DELAYED DISC SURGERY ON MUSCULAR PARESIS

HENRIK WEBER

Accepted 9 v 75

Sciatica caused by disc lesions is a common disease which can cause neurological deficits of the lower extremities and can be treated by physiotherapy and/or surgery

The general attitude has been to operate only when conservative treatment fails, except, of course, if alarming and definite indications, such as intolerable pain, bladder and rectal paresis, persistent and marked deviation of the spine, and acute motor paresis necessitate surgical intervention

All of these symptoms may occur in different combinations There is some uncertainty, however, as to whether or not existing muscular paresis of unknown duration is an indication for surgical intervention

A survey of the literature reveals that several authors have examined operated and non operated patients retrospectively, and have compared the outcome of the paresis in the two groups (Eie 1964, Hakelius 1970, Weber 1970) Hakelius found that approximately 50 per cent, and Weber that about 80 per cent of the patients in both groups had regained full neuromuscular function, while Eie achieved complete or partial restitution of the paresis in 93 per cent of his surgically treated patients

All these evaluations are based on traditional neurological manual techniques, and cannot, therefore, be registered objectively Furthermore, the methods of selecting the patient material resulted in groups which are not readily comparable

On the whole, there is little information in the available literature which may serve to indicate the significance of paresis as an indication for surgical treatment of the lumbar disc prolapse In order to contribute to the solution of this problem we added a quantitative muscle registration technique to a prospective study which was carried out in

patients suffering from sciatica with a myelographically verified disc prolapse Conditions at the Department of Neurology, Ullevål Hospital are well suited for a study of this kind, because about 150 patients with lumbar disc prolapse are admitted annually to this department, and because a quantitative method for the objective measurement of muscular strength of the muscle groups of the lower extremities has been established (Weber 1973) We hoped at the same time to determine which muscle groups become paretic according to which root has been injured

## MATERIAL

Originally the material consisted of 280 patients comprising all patients who had been admitted to the department during 1970 and 1971 with symptoms of an affection of the $L_5$ and $S_1$ roots as well as a positive myelogram i e a roentgenological finding showing impression in the dural sac and/or increased width of the root and shortening of the root sleeve The myelography was carried out with a water soluble contrast medium (Myelotrast, "A L")

After 14 days of observation in the department the 280 patients were divided into three groups according to the following criteria

1 The doubtful group, selected at random among patients between 30 and 55 years of age who because of doubt as to the choice of therapy received treatment by drawing lots
2 Patients with moderate symptoms and/or continuous improvement as the result of physical therapy and medical treatment
3 Patients with persistent and/or progressive symptoms of a more serious nature which indicated surgical intervention (operated)

Pareses were observed in 133 patients and 128 of these attended the follow up examination after 1 year Three patients had moved abroad and two could not be traced

Of the 128 patients 64 belonged to Group 1 32 were operated upon and 31 were treated conservatively One female patient had to be excluded because of lack of cooperation

## METHOD

Because nerve root pain interferes with motor effort the patients were treated with bed rest and analgetics for 14 days whereafter pain was no problem in this respect

The 14 day period meant that it was not possible to observe the effect of surgery in the acute stage On the other hand the advantage of the method chosen was greater accuracy in measuring the muscle strength

The motor function was examined and checked daily by the conventional manual technique At the same time the patients underwent training and received instructions in preparation for the tests

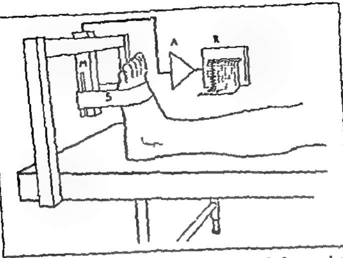


*Figure 1 Measurement of strength in the muscle groups which cause dorsal flexion of the foot*

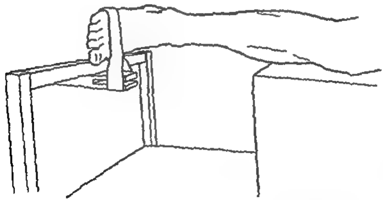

*Figure 2 Measurement of strength in the muscle groups which evert the foot*

Two weeks after admission and prior to any operative treatment the maximal strength of the muscles of the lower limbs was measured during the maximal isometric voluntary contraction This examination was repeated 1 year after discharge The maximal isometric muscle strength is defined as the maximal force which the muscle can develop and maintain for a brief period of time (1–2 seconds) The examination took place on a bench With the aid of a non stretchable strap the foot was fixed to a measurement beam with built in strain gauges The electrical signals were transferred to a direct recorder which showed the deflections on squared paper The following muscular functions were recorded dorsal extension of the big toe the four lateral toes and the entire foot (Figure 1) eversion of the

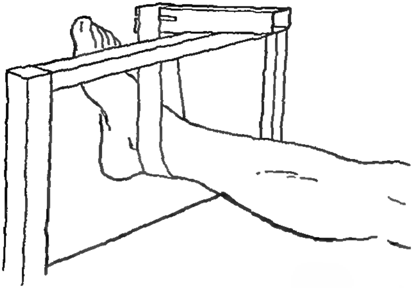

*Figure 3 Measurement of strength in the muscle groups which extend the hip in the supine position.*

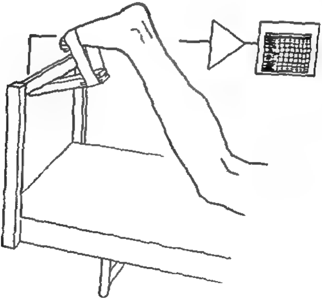

*Figure 4 Measurement of strength in the muscle groups which cause plantar flexion of the foot in the prone position*

foot (Figure 2), abduction and extension of the leg (Figure 3), and flexion of the foot (Figure 4) and the knee (Figure 5) Two contractions were recorded, and the mean of the two tabulated When the difference between the two measurements exceeded 5 per cent of the deflexion, a third measurement was performed Thus, in all cases, two recordings were obtained which met the established requirements Corresponding muscle groups were examined alternately in the healthy and in the

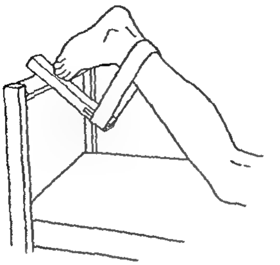

*Figure 5* *Measurement of strength in the muscle groups which cause flexion of the the knee in the prone position*

afflicted leg with exactly the same starting position In order to diminish back pain during muscle contraction pillows were suitably placed and the patient strapped to the bench to give the necessary support for the leg hip and back

On the basis of control experiments in 13 healthy persons with a total of 104 measurements it was found that the difference in strength between the two legs might normally differ as much as 20 per cent Consequently only loss of strength in excess of 20 per cent was recorded as paresis This large margin of safety probably eliminated several cases with slight paresis but the exclusion of false positive findings was in the examiner's opinion of greater importance Control measurements of 6 patients made on several consecutive days showed that the deviations as a rule fell well within a limit of 20 per cent

The measured strength in the afflicted leg before and after treatment was expressed in per cent of the corresponding strength in the healthy leg Fifty per cent loss of strength therefore means half strength, and 100 per cent loss means complete paralysis The figures were rounded off to the nearest 5 per cent A recorded difference in muscle strength exceeding 20 per cent during the course of the observation year was interpreted as a real deterioration or improvement

The *conservative treatment* consisted of bed rest and muscle training Abdominal and back muscles were trained isometrically and the muscles of the extremities isotonically A considerable amount of time was devoted to instructing the patient in the technique of ergonomics

The *surgical treatment* consisted of extirpation of the prolapse and loose disc tissue with the patient in a prone position with hips and knees flexed All the operations were performed at the Department of Neurosurgery Ullevål Hospital but by various surgeons

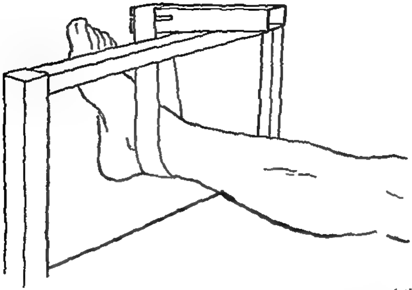

*Figure 3 Measurement of strength in the muscle groups which extend the hip in the supine position*

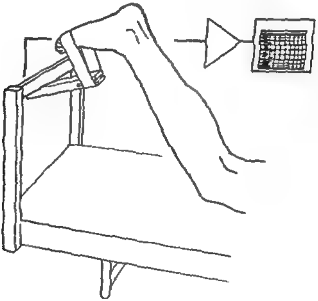

*Figure 4 Measurement of strength in the muscle groups which cause plantar flexion of the foot in the prone position*

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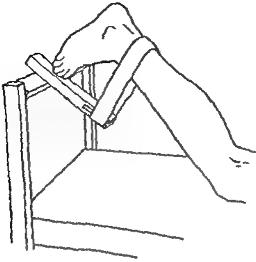

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## RESULTS

The results yielded information on two conditions of significant interest,

1. Comparison of the development of paresis in the operated and the non-operated patients in the group selected at random (Group I).
2. Information as to which muscle groups are affected by disc prolapse corresponding to the disc $L_4$–$L_5$ (usually $L_5$-root affection) and the disc $L_5$–$S_1$ (usually $S_1$-root affection) respectively

Surprisingly enough, the study shows that the prognosis with respect to motor restitution is no better after surgery than after conservative treatment (Tables 1 and 2). In fact, measurements of strength during dorsal movement and flexion of the foot and the toes showed even poorer results in the operated patients The same pattern is also apparent when comparing the other two groups (II and III).

*Table 1. Muscle strength at the control examination of patients in Group 1*

| | Dorsal movement of the foot | | Abduction + extension of the hip, flexion of the knee | |
|---|---|---|---|---|
| | Operated % | Conservative % | Operated % | Conservative % |
| Well (complete restitution) | 47 | 73 | 67 | 70 |
| Improved (partial restitution) | 24 | 4 | 2 | 5 |
| Unchanged | 23 | 4 | 22 | 19 |
| Deteriorated | 7 | 20 | 9 | 5 |
| Total number of measurements | 62 | 56 | 45 | 37 |

*Table 2 Muscle strength at the control examination of patients in Group 1*

| | Flexion of the foot | | Eversion of the foot | |
|---|---|---|---|---|
| | Operated % | Conservative % | Operated % | Conservative % |
| Well (complete restitution) | 56 | 75 | 47 | 50 |
| Improved (partial restitution) | [illegible] | 5 | 18 | 16 |
| Unchanged | 25 | 15 | 18 | 27 |
| Deteriorated | 13 | 5 | 18 | 7 |
| Total number of measurements | 16 | 20 | 17 | 18 |

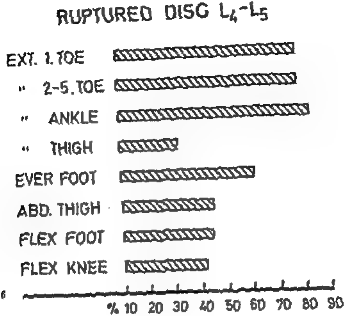


Figure 6

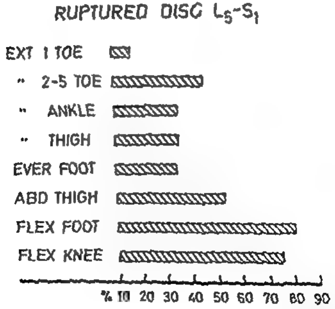


Figure 7

*Figures 6 and 7. Showing the percentage distribution of the paresis in the lower extremities in patients with disc prolapse corresponding to the discs $L_4$–$L_5$, and $L_5$–$S_1$.*

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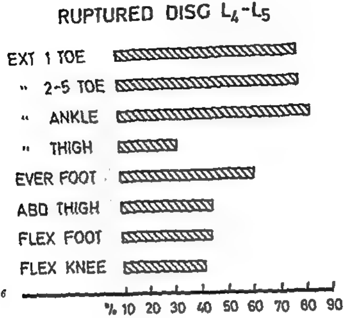


*Figure 6*

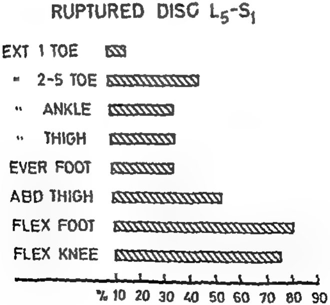


*Figure 7*

*Figures 6 and 7 Showing the percentage distribution of the paresis in the lower extremities in patients with disc prolapse corresponding to the discs $L_4$-$L_5$ and $L_5$-$S_1$*

In agreement with clinical experience, Figures 6 and 7 show that the paresis in the case of an $L_5$-*lesion is mainly localized in the muscle* groups which dorsally flex or evert the foot. Somewhat unexpectedly, it was observed that 30–40 per cent of the other muscle groups of the lower extremities were also affected. The same is observed in $S_1$-lesions where paresis may be demonstrated in all the muscle groups in addition *to the dominating loss of strength in the flexors of the foot and knee.*

Paresis of 80 per cent or more was observed in only 9 of the 280 patients included in the follow-up study. Of these, six were operated, three of whom had a 50 per cent improvement and one had a 90 per cent improvement, while two showed no change. In two of the three patients who were *treated conservatively, the paralysis persisted, while* one patient showed improvement.

In the entire material more than 70 per cent of all pareses were partially or completely restored, but only about 30 per cent of the patients had regained full strength in all muscle groups.

## DISCUSSION

How can it be explained that surgical therapy gives no better prognosis for the pareses than does conservative treatment? *Offhand one would* expect that a surgical decompression should give the best possibility for the reestablishment of the conduction ability of the nerve roots.

Part of the explanation is probably to be found in the fact that the axons of the roots already have suffered irreparable damage by the time the operation *is performed. The ability of the nerves to tolerate* mechanical trauma depends mainly on the type of onset—acute or insidious—and on the degree and the duration of the compression, and it cannot be excluded that a 14-day stay in the hospital, in addition to time spent waiting for admission to the hospital, has diminished the possibility *of the nerve root to rapidly regenerate.* Consequently, if surgical decompression can be performed immediately after the paresis has occurred, this should be considered adequate therapy until new evidence indicates another procedure. Dahlgren (1963) has shown that results of operative treatment in the acute stage are completely comparable with other follow-up studies of operated discs concerning the nerve root pain.

The problem is that one seldom can obtain definite information about the time of onset of the paresis, because the patient himself,

surprisingly enough, is often unaware of any loss of motor function He is concerned with sensory phenomena such as pain, sensation of cold and paraesthesia and any reduction of these qualities often is referred to by the patient as improvement Furthermore, the assessment of muscular strength in sciatic patients who are suffering from pain may be difficult so paresis may be easily over- and under estimated (Weber 1970) The intensity of the pain itself is an unreliable yard-stick for the grading of root lesions, furthermore, different patients have different pain tolerance For these reasons the general practitioner naturally assumes a wait and see attitude, with the result that the appearance of pareses is overlooked

Theoretically one would primarily expect loss of function in the thick nerve fibres of the root which are more vulnerable to compression than the thin fibres But the considerable variation, both in degree and in quality, of the neurological symptoms which are seen in sciatic patients indicates that the root lesion is a result of a more complicated traumatization than purely a mechanical compression alone The explanation lies probably within factors such as oedema, blood circulation failure and chemical changes

A possibility of damage is also present during the operation itself, because the surgical technique, the complicated space conditions, haemorrhages, loss of muscle defence during the operation and secondary adhesions are all potential risk factors Previous observations have also shown that operative extirpation of a herniated disc causes weakened ankle jerk as well as the occurrence of troublesome leg cramps during the night to a much greater extent than is the case with the non operated patients (Weber 1970)

The prognosis in the case of complete paralysis of the dorsal flexors of the foot (*drop foot*) has been examined postoperatively without finding any correlation between factors such as time since onset, duration or findings during the actual operation (prolapse or protrusion) on the one hand and the restitution of the muscular function on the other (Andersson & Carlsson 1966) This finding may perhaps also suggest that motor damage develops so *rapidly* that surgical therapy seldom can be performed early enough

Clinical experience shows that all muscle groups in the lower extremities may be subject to paresis in the case of root lesion caused by lumbar disc prolapse (Kristiansen 1962, Thompson 1970 Stauffer 1971) The distribution of dysfunction as shown by this study is of interest and underlines the importance of undertaking a complete

In agreement with clinical experience, Figures 6 and 7 show that the paresis in the case of an $L_5$-lesion is mainly localized in the muscle groups which dorsally flex or evert the foot Somewhat unexpectedly, it was observed that 30–40 per cent of the other muscle groups of the lower extremities were also affected The same is observed in $S_1$-lesions, where paresis may be demonstrated in all the muscle groups in addition to the dominating loss of strength in the flexors of the foot and knee

Paresis of 80 per cent or more was observed in only 9 of the 280 patients included in the follow-up study Of these, six were operated, three of whom had a 50 per cent improvement and one had a 90 per cent improvement, while two showed no change In two of the three patients who were treated conservatively, the paralysis persisted, while one patient showed improvement

In the entire material more than 70 per cent of all pareses were partially or completely restored, but only about 30 per cent of the patients had regained full strength in all muscle groups

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The problem is that one seldom can obtain definite information about the time of onset of the paresis, because the patient himself,

## SUMMARY

A prospective study was carried out in 280 patients suffering from sciatica caused by myelographically verified disc prolapse The patients were divided into three groups according to the following criteria

1 *The doubtful group, selected at random*
  Patients with doubtful indications for surgery Treated operatively or not—by drawing lots
2 *Non-operated group*
  Patients with moderate symptoms and/or continued improvement
3 *Operated group*
  Patients with imperative indications for surgery

The muscle strength of the lower limbs was measured during maximal isometric voluntary contractions in all the patients 2 weeks after admission Approximately 50 per cent had paresis Control examinations of these patients 1 year later showed that operative treatment gave no better prognosis than conservative treatment with regard to the motor function, neither in the group chosen at random nor in the selected groups The causative factors are discussed



## ACKNOWLEDGEMENTS

I should like to thank *Norsk Kollektiv Pensjonskasse A.S* for the generous support which made this investigation possible


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examination of the functional state of all the involved muscles in sciatic patients

It should be pointed out that EMG may reveal persistent signs of denervation in a muscle even though a clinical test of muscle strength may appear normal. However, since EMG cannot establish the loss of function in a quantitative manner, and since slight paresis is of little consequence for the functional capacity of the patient due to the compensating mechanisms, little is to be gained, from a practical point of view, by such additional examination.

Objection may be raised to the fact that the total function of the muscles should not be judged entirely on the basis of the measurement of isometric muscular strength. The answer to this statement is that if a paresis attains a degree which produces noticeable reduction in the function of the extremity, it will also be detectable by isometric testing which should be preferred because it requires less complicated methods than the measurement of the other qualities (Hermansen et al. 1972).

According to clinical experience, muscle function still shows improvement more than 1 year after nerve damage in sciatic patients. This can partly be explained by nerve conduction reestablishment following Wallerian degeneration. Consequently, a reexamination is now carried out after an observation period of 4 years to achieve a more correct picture of the prognostic trend.

## CONCLUSION

The present study shows that the prognosis of the disturbed motor function in sciatica is not better after delayed surgical therapy than after conservative treatment during the first year of observation.

Therefore, the loss of muscle strength presents a doubtful indication for surgical treatment. If, however, surgical decompression can be performed immediately after the paresis has occurred, this should be considered adequate therapy until new evidence indicates another procedure.

The small number of patients who had complete or almost complete paralysis does not permit any conclusions to be made with regard to the effect of the type of treatment used.

Acta orthop scand 46 643 650 1975

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# PARA ARTICULAR OSSIFICATIONS AFTER PRIMARY PROSTHETIC REPLACEMENT *AD MODUM* AUSTIN T MOORE

JØRGEN ØRNSHOLT & JENS O ESPERSEN

Accepted 20 1 75

The occurrence of para articular ossifications after alloarthroplasties of the hip has been a recognized complication since the first announcement of the results of these procedures In the past few years para articular ossifications have been increasingly mentioned in papers concerning results of total hip replacement However, there is a great variation in the information given of the frequency of ectopic ossifications and in the same way the clinical importance has so far only been sparingly elucidated

It is the purpose of this study to describe the frequency and the clinical consequences of para articular ossifications after primary prosthetic replacement using Austin T Moore's technique in the treatment of medial fractures of the femoral neck

## MATERIAL AND METHODS

At the Department of Orthopaedic Surgery Aarhus Municipal Hospital the treatment of unstable medial fractures of the femoral neck in patients older than 60 years has been since 1962 primary prosthetic replacement *ad modum* Moore

The operative procedure has been Moore's posterior approach and inverted T-capsular opening The femoral neck has been shaped either by chisel Giglie's saw or by Stryker's reciprocating bone saw and in no case was the capsule removed Only Vitallium prostheses have been used

The post operative treatment involved bedrest for 3 weeks and weightbearing walking training 4 weeks after the operation X ray examination was performed routinely immediately after the operation then monthly for the following 3 months and finally every 3 months until the follow up period concluded 1 2 years later

During the period January 1964 April 1967 a total of 127 patients (102 females

Weber, H (1970) An evaluation of conservative and surgical treatment of lumbar disc protrusion. *J Oslo City Hosp* 20, 81–93
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*Key words*: intervertebral disk displacement; sciatica; paresis, prognosis

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*Figure 2.* Characteristic examples of the grades of para articular ossifications A grade 0 B grade I, C grade II, D grade III

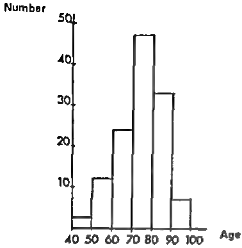


*Figure 1 Age distribution*

and 25 males) have had a Moore prosthesis fitted as a routine treatment for unstable medial fractures of the femoral neck Excluded are the patients suffering from severe osteoarthritis and rheumatoid arthritis

The age distribution is shown in Figure 1 The oldest patient was 99 years of age and the youngest 49 at the time of operation giving a mean age of 74 8 years

The reason why 15 patients younger than 60 years were included was complicating disease which made early mobilization desirable or gave difficulties in an attempt to nail

The time which elapsed from admission until surgery is shown in Table 1 Fifteen patients died before discharge from the department six of these died before the first radiographic examination 1 month after the operation Sixty two patients were followed in the outpatient clinic for 1 2 years after the operation Forty six patients were alive 5–7¼ years postoperatively Of these patients 40 (87 per cent) have been followed up Four refused to co operate and two were abroad The para articular ossifications were determined on review of all the supine anteroposterior roentgenograms of the hip that were available for the whole group of patients All the films were studied by both authors

The ossifications are classified in accordance with the following grading system

| | |
|---|---|
| Grade 0 | no para articular ossifications or exostose formations (Figure 2 A) |
| Grade I | small ossifications with largest diameter < 1 2 cm (Figure 2 B) |
| Grade II | middle sized ossifications with diameter > 1 2 cm but no apparent bridge building (Figure 2 C) |
| Grade III | large ossifications bridging the space between femur and pelvis (Figure 2 D) |

*Table 1 Period from admission to the hospital until operation was performed*

| Days | 1 | 2 | 3 | 4 | 5 | 6–10 | 10–20 | 20–30 |
|---|---|---|---|---|---|---|---|---|
| No of patients | 50 | 42 | 18 | 7 | 3 | 3 | 2 | [illegible] |

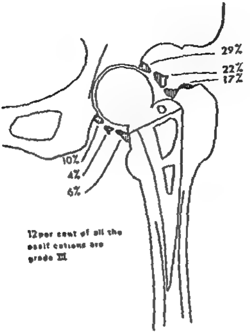


*Figure 3 Localization of grade I and grade II para articular ossifications*

*Follow-up examination*

At the re examination (5–7½ years postoperatively) the para-articular ossifications did not have a significantly changed X ray configuration from the time of the final examination in the outpatient clinic 1 2 years after the operation Thus, except for the four previously-mentioned patients, no changes in the extent of the ossifications from the roentgenograms 3 months after the operation were observed

The patients examined were represented in the four groups, accord-

*Table 4 The four ossification grades in relation to bone absorption*

| | | Number of patients |
|---|---|---|
| Grade | 0 | 14 |
| " | I | 10 |
| " | II | 5 |
| " | III | 2 |
| | Total | 31 |

*Table 2 Results in 121 radiologically examined patients*

| Para-articular ossifications according to grades | Number of patients | | Percentage | |
|---|---|---|---|---|
| Grade 0 | 67 | | 55 | |
| „ I | 36 | 54 | 30 | 45 |
| „ II | 11 | | 9 | |
| „ III | 7 | | 6 | |
| Total | 121 | | 100 | |

## RESULTS

The distribution of para-articular ossifications according to the abovementioned grading system in the 121 patients with X-ray film available after surgery is shown in Table 2

The ossifications had reached their final size within 3 months after the operation in all cases except four In two cases grade I ossifications arose later than 3 months after the operation, but it is possible that these ossifications could have been pointed out earlier had better X-ray techniques been used The remaining two patients had deep infections and later developed ossifications of grade III

The localization of all the ossifications and the mutual per cent distribution is shown in Figure 3 Table 3 shows the frequency of postoperative complications in the four groups

Bone absorption with settling of the prosthesis more than 5 mm was found in 31 patients (26 per cent) There was no significant correlation between the occurrence of para-articular ossifications and the tendency for bone absorption (Table 4) No correlation could be found between the shaping method saws or chisel—and the ossifications

*Table 3 The ossification grades in relation to complications*

| | Number of patients | Infection | Haemorrhage | Dislocation |
|---|---|---|---|---|
| Grade 0 | (67) | 4 | 5 | 1 |
| „ I | (36) | 3 | 2 | 1 |
| „ II | (11) | 2 | 0 | 0 |
| „ III | ( 7) | 4 | [illegible] | 1 |
| Totals | (121) | 13 | 12 | 3 |

shadows to those of enormous size apparently bridge-building bone formations

This material confirms that ossifications of considerable size can be seen after deep infection However no direct correlation between deeper infection or haematoma and ectopic ossifications is shown There is no correlation between a tendency for bone absorption and formation of para articular ossifications

Moore & Lunceford (1960) reported that excessive proliferation of bone is seen in a few cases after fitting of a self locking hip prosthesis

Charnley (1972) postulated that a "notable degree of ectopic ossification is found in 5 per cent of cases after total hip replacement and only affects the mobility to a small degree

Brooker et al (1973) set up a grading system in which class I and II corresponds to grade II in this study According to their classification ossification occurred in 21 per cent of the cases and only 2 per cent developed bone formations affecting the mobility

Nollen & Slooff (1973) reported a frequency of para articular ossifications of approximately 50 per cent in 155 patients following total hip replacement according to Muller & Mackee s technique Only some of the patients with the largest ossifications had limitation of mobility

Anderson & Nielsen (1972) studied the results after arthroplasty of the hip using Moore s prosthesis according to the various indications for surgery They found ossifications in 41 out of 77 patients but did not mention whether these affected the functional results

Thomassen et al (1974) found that disabling conditions after a Moore prosthetic replacement were caused by other diseases and no correlation between hip function and ossifications was mentioned

In the follow up examination in this study we found two patients (5 per cent) with grade III ossifications that might have been responsible for a poor hip function Otherwise the majority of the ossifications in our cases were small and seemingly without any clinical importance

There seems to be a good correlation between the communications about frequency and clinical importance of ectopic ossifications after hip replacement and para articular ossifications after Moore prosthetic replacement in the treatment of medial fractures of the femoral neck

## SUMMARY

This study concerns the frequency of para articular ossifications after primary prosthetic replacement *ad modum* Austin T Moore in the

*Table 5 Results at the follow-up study in 40 patients according to the grade of para articular ossifications represented*

| | Number of patients | Ability to walk | | | Hip mobility | | | Information about pain | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | with or without 1 stick | with 2 sticks or crutches | inability to walk | > 211° | 161–210° | < 160° | without pain | pain on walking | pain at rest |
| Grade 0 | 23 | 17 | 5 | 1 | 9 | 11 | 3 | 12 | 10 | 1 |
| Grade I | 13 | 11 | 2 | 0 | 4 | 6 | 3 | 6 | 6 | 1 |
| Grade II | 2 | 1 | 1 | 0 | 0 | 1 | 1 | 2 | 0 | 0 |
| Grade III | 2 | 0 | 1 | 1 | 0 | 0 | 2 | 1 | 0 | 1 |
| Totals | 40 | 29 | 9 | 2 | 13 | 18 | 9 | 21 | 16 | 3 |

The hip mobility is calculated as the sum of degrees of passive movement extension/flexion—abduction—adduction—internal rotation and external rotation

ing to the degree of para-articular ossifications, in the same ratio as the total material (Table 5) There was no characteristic correlation between the size of the ossifications and the hip joint function, except for the considerable limitation of movement, which was found in the cases with grade III ossifications

## DISCUSSION

Para-articular ossifications after prosthetic replacement *ad modum* Austin Moore have been found in this material in 45 per cent of 121 patients (Table 2) The evaluation of the roentgenograms has been made in such a way that all degrees of calcific shadows are included from the smallest ones, which occur as beak-shaped exosthoses or detached

Acta orthop scand 46, 651–653, 1975

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# COMMINUTED INTERTROCHANTERIC FRACTURE OF THE FEMORAL NECK

Vagn Kolind Sorensen

Accepted 28 iii 75

The incidence of complications following nailing of comminuted intertrochanteric fractures of the femoral neck was studied

## MATERIAL AND METHOD

During the period 1965–1970 a total of 71 patients with the above mentioned type of fracture were treated, all by operation

The fracture was reduced under fluoroscopy, as near to an anatomical position as possible, and fixed with a nail (McLaughlin 1947)

Avulsed fragments, either medial or from the trochanteric area, were not fixed.

One week after the operation the patients were allowed to sit and in another week walking training with assistance was started As soon as the patients could manage on their own they were discharged and thereafter seen in the Outpatient Department every 3 or 6 months for the next 2 years

## RESULTS

There were 38 complications

In 20 cases the osteosynthesis broke down, resulting in varus deformity Reoperation was performed in seven

Infection occurred in 15 cases, deep in 11 and superficial in four

Decubitus ulcer developed in one case, thrombophelbitis in one, and there was one case of non-union

At the end of 2 years 43 of the patients were still alive Two were confined to bed and had to be nursed, and seven were in wheelchairs

Three were able to walk around a bit with crutches Thirty-one could walk, many of them using a stick out of doors

treatment of unstable fractures of the femoral neck In 121 patients who were X-rayed after surgery ossifications were found in 45 per cent of the cases Patients that preoperatively had severe coxarthritis or rheumatoid arthritis are excluded Two thirds of the bone formations described were very small and without clinical importance About 20 per cent of the ossifications were of a considerable size but no clinical consequences could be demonstrated About 12 per cent of the ossifications—6 per cent of all the patients in this study—were large and only in this group could a compromised hip function be found It seems as the process of ossification is limited to the first 3 post operative months

There is a good correlation between the communications regarding ectopic bone formation after total hip replacement and the frequency found in this study

ACKNOWLEDGEMENT

We are grateful to I Moselilde MD chief radiologist who kindly gave permission to use the X ray material

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*Key words* para articular ossifications ectopic bone formation Moore s prosthesis femoral neck fracture

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Acta orthop scand 46, 651–653, 1975

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# COMMINUTED INTERTROCHANTERIC FRACTURE OF THE FEMORAL NECK

VAGN KOLIND-SØRENSEN

Accepted 28 iii 75

The incidence of complications following nailing of comminuted intertrochanteric fractures of the femoral neck was studied

## MATERIAL AND METHOD

During the period 1965–1970 a total of 71 patients with the above mentioned type of fracture were treated, all by operation

The fracture was reduced under fluoroscopy, as near to an anatomical position as possible and fixed with a nail (McLaughlin 1947)

Avulsed fragments either medial or from the trochanteric area, were not fixed

One week after the operation the patients were allowed to sit, and in another week walking training with assistance was started As soon as the patients could manage on their own they were discharged and thereafter seen in the Outpatient Department every 3 or 6 months for the next 2 years

## RESULTS

There were 38 complications

In 20 cases the osteosynthesis broke down, resulting in varus deformity Reoperation was performed in seven

Infection occurred in 15 cases, deep in 11 and superficial in four

Decubitus ulcer developed in one case, thrombophlebitis in one, and there was one case of non-union

At the end of 2 years 43 of the patients were still alive Two were [illegible] in wheelchairs [illegible] Thirty-one could [illegible], many of them using a stick out of doors

## DISCUSSION

An intertrochanteric fracture of the femoral neck may be comminuted often with crushing or avulsion of a large *posterior fragment* or of the medial cortex of the neck, so that it is not possible to reconstruct a stable bony buttress (Evans 1949, Dimon & Hughston 1967)

These fractures are difficult to stabilize by *osteosynthesis*, and Evans (1949) suggested nailing them in the deformed position without attempting reduction, whereas Clawson (1957) and Bahr (1963) have recommended traction

Another possibility is to nail these fractures in valgus (Riska 1971) or to perform a displacement osteotomy (Dimon & Hughston 1967, Debrunner & Cech 1969, Harrington & Johnston 1973)

## CONCLUSION

The comminuted intertrochanteric fractures of the femoral neck reported here had been treated in the same way as simple fractures, i e with reduction, nailing, and early weightbearing

Complications occurred in more than half the cases, most often in the form of failure of the osteosynthesis in varus deformity, next most frequently in the form of infection

The operative method is difficult, takes a long time in the case of comminuted fractures, and does not secure stable fixation

If operative treatment is to be used at all in these fractures, it ought to take the form of fixation of all fragments or of a displacement osteotomy

The time of commencing weightbearing should be accurately adapted to the surgeon's impression concerning the stability of the osteosynthesis

## SUMMARY

If comminuted intertrochanteric fractures of the femoral neck are treated in the same way as the simple ones— by reduction, McLaughlin nailing, and early weightbearing—many complications will occur, in most cases failure of the osteosynthesis or infection If operation is to be used at all in these fractures, it must take the form of a firmer fixation or primary osteotomy *Moreover, the time of commencement* of weightbearing must be accurately and individually determined

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*Key words* postoperative complications, femoral neck fractures, fracture fixation internal intertrochanteric femoral neck fractures

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# MORTALITY IN INTERTROCHANTERIC FRACTURE OF THE FEMORAL NECK

VAGN KOLIND-SØRENSEN

Accepted 28 iii 75

The mortality among patients subjected to operation for intertrochanteric fracture of the femoral neck was studied and related to preceding cardiological status

## MATERIAL AND METHOD

During the period 1965–1970, a total of 209 patients with intertrochanteric fracture of the femoral neck were treated in the Århus Municipal Hospital, all by operation (McLaughlin 1947)

Prior to surgery, patients with signs of heart disease were examined by a cardiologist who assessed the operative risk Even if it were assessed as increased operation was carried out, as long lasting traction was believed to be even more dangerous Premedication with digitalis or diuretics was administered in many cases

If death or time of death were not apparent from the case notes, inquiries were sent to the national registry

## RESULTS

Out of the 209 patients, 61 were under 70 years of age, 65 were 70–80, and 83 were over 80 years old

At the end of 1 year 62 of the 209 patients had died

In 162 of the 209 patients the operative risk had not been believed to be increased Among them 32 succumbed during the first year

In the remaining 47 the operative risk was deemed to be increased, and of these 30 died within the first year

## DISCUSSION

An important reason for introducing operative treatment for femoral neck fractures was that this was believed to reduce the mortality, which must therefore be checked constantly

Evans reported in 1951 that the mortality ranged from 10 to 40 per cent after conservative treatment and between 10 and 25 per cent after operation. According to Aronsson (1950) the mortality had dropped from 16 to 8 per cent and according to Robey (1956) from 50 to 20 per cent after the introduction of operative treatment. Storen (1956) found a mortality of around 10 per cent among operated as well as among conservatively treated patients. Among operated patients Boettcher & Riese (1970) found a mortality of 18 per cent.

In general the mortality is stated as the percentage of patients dying in hospital or within the first month. But as demonstrated by Hansen & Neidhardt (1970) there is a considerable additional mortality during the first months. At the end of one year these authors found that 40 per cent of the patients had died.

Lindholm et al. (1971) reported that deaths among patients with fractures of the femoral neck were by far most often due to heart disease. The present author studied the mortality in cases where preoperative cardiological examination had revealed an increased operative risk and in others where it had not.

## CONCLUSION

Among a population group like the one under discussion the mortality is normally rather more than 10 per cent per annum (Danmarks Statistik, Copenhagen 1973).

In the present material it was about 30 per cent within one year.

In three quarters of the patients preoperative cardiological examination had not shown an increased operative risk. In this group the mortality during the first year was about 20 per cent. In other words among the great majority of elderly patients who do not exhibit significant cardiac disease despite their advanced age the excess mortality following trauma and operation is less than 10 per cent.

Among the remaining one quarter of the patients in whom the operative risk was deemed increased the mortality during the first year was about 60 per cent.

## SUMMARY

The mortality during the first year after operation was studied in 209 patients with intertrochanteric fracture of the femoral neck all treated with osteosynthesis.

The excess mortality due to the fracture and operation proved to be about 20 per cent Among the great majority of patients who did not have significant cardiac symptoms or signs despite their advanced age, the excess mortality was below 10 per cent Among patients whose operative risk had been deemed increased due to heart disease, the excess mortality during the first year was about 50 per cent

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# THE INFLUENCE OF ACRYLIC CEMENT ON THE FEMUR OF THE DOG

## A Histological Study

J Lindwer & A van den Hooff

Accepted 8 i 75

Serious deformation of the hip joint is increasingly treated with total hip replacement arthroplasty, the artificial bearings being fixed in the skeleton by self curing methylmethacrylate ("acrylic cement")

It is of considerable importance to get an insight into the way in which the bone of the femur reacts to insertion of the polymer A number of observations have been reported, made on material obtained from patients who had been wearing such a prosthesis fixed with acrylic cement for a number of years (Willert & Schreiber 1969, Charnley 1970 Willert & Puls 1972) The authors describe necrosis of the bone occurring around the cement, followed by repair processes, a sequence leading to the situation in which there is no longer a direct contact between bone and cement Formation of connective tissue in which multinucleated giant cells are present is seen also

In papers reviewing clinical results (Parsons 1969, Enderle 1972) mention is made of a loosening of the prosthesis, a complication which possibly is due to changes in the surrounding tissue

Tissue damage can be the consequence of the local rise of temperature which accompanies polymerization Another factor can be the non-inertness of the acrylic cement Various components can escape from the polymerizing mixture a residue of the monomer, hydroquinone, dimethylparatoluidine and benzoylperoxide In the long run it is oligomeric methacrylate, formaldehyde and methacrylic acid which may find their way to the tissues (Mark & Mesrobian 1950, Oppenheimer et al 1955 Ridley 1957, Hastings 1968)

A number of workers (Wiltse et al 1957, Rietz 1968, Slooff 1970) have performed animal experiments to study the influence on the

The excess mortality due to the fracture and operation proved to be about 20 per cent. Among the great majority of patients who did not have significant cardiac symptoms or signs despite their advanced age the excess *mortality was below 10 per cent. Among patients* whose operative risk had been deemed increased due to heart disease the excess mortality during the first year was about 50 per cent.

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*Table 1 Type of operation breed survival time and number of dogs used in each type of operation The column at the right denotes whether the medullar cavity was emptied and filled with acrylic cement (exp) or just emptied (C) L = left femur R = right femur*

| Survival time after operation | Breed | Number | Type of operation L | R | L | R |
|---|---|---|---|---|---|---|
| 24 hours | mongrel | 2 | Exp | C | Exp | – |
| 2 weeks | mongrel | 2 | Exp | C | Exp | – |
| 4 weeks | beagle | 2 | Exp | C | Exp | – |
| 8 weeks | beagle | 2 | Exp | C | Exp | C |
| 12 weeks | beagle | 2 | Exp | C | Exp | – |
| 16 weeks | beagle | 1 | Exp | C | | |
| 20 weeks | beagle | 2 | Exp | C | Exp | C |
| 28 weeks | beagle | 1 | Exp | – | | |
| 10 months | mongrel | 1 | Exp | – | | |
| 12 months | mongrel | 2 | Exp | – | Exp | – |
| 15 months | mongrel | 1 | Exp | – | | |
| 18 months | mongrel | 2 | Exp | | Exp | – |
| 21 months | mongrel | 2 | Exp | – | | |

Under general anesthesia the left femur was exposed The periosteum was removed in two places 5 cm distal to the trochanter major and 3 cm proximal to the knee joint At each location a hole 8 mm in diameter was drilled The cancellous bone between the holes was removed and the bone marrow was sucked off through the distal hole The cavity thus prepared was filled with prepolymerized methacrylate employing a specially designed syringe with a screw thread piston Care was taken to avoid high pressure during insertion

In eight dogs temperature measurements were performed using a thermocouple details are given under Results

In a number of animals a control operation was performed after complete emptying no methacrylate was inserted The experiments are listed in Table 1

For histological study the following techniques were used Three disks were taken from each femur one just distal to the upper hole one from the middle of the shaft and one proximal to the bottom hole Half of each disk was fixed in Darling ton s fixative (100 parts 90 per cent ethanol, 40 parts undiluted neutral formalin 7 parts acetic acid) and decalcified electrolytically in a formalin nitric acid mixture In the course of dehydration methacrylate was dissolved in chloroform The stains used were hematoxylin phloxin Mallory stain and a combined Alcian Blue P.A.S method

The other halves of the bone disks were fixed in 80 per cent ethanol and embedded in polymethyl methacrylate Microradiographs were prepared using 100 micron thick slices of this material

cortical bone of acrylic cement present in the medullar space These authors described a necrosis of the inner part of the cortex, which they attributed both to a disturbance of the circulation and to the heat of polymerization Further mention is made of the formation of connective tissue around the cement and the formation of new bone on the periosteal surface of the bone

A number of investigations (Ohnsorge & Goebel 1969, Bloch et al 1970) have shown that the rise of temperature resulting from polymerization after insertion of the prosthesis can be responsible for tissue necrosis It has also become apparent that inserting a foreign body into the medullary cavity of long bone in itself disturbs the circulation, which in turn leads to alterations in the surrounding cortical bone (Trueta & Cavadias 1955, Danckwardt-Lillieström et al 1970) The changes consist of necrosis of the inner part of the cortex and the apposition of periosteal bone around the shaft

Thus, a number of causative factors may be mentioned which lead to alterations of the bone after insertion of a prosthesis

a a mechanical injury as a consequence of the trauma of insertion
b a disturbance of vascularization by interrupting the marrow circulation
c a rise in temperature during polymerization
d the escape of non-inert substances from the acrylic cement

The factors mentioned under a, b and c will in the course of time lose their significance The liberation of noxious substances, however, may play a role both at an early and at a later stage

The question underlying the present investigation was what is the influence of acrylic cement on bone, a) in the short term, b) in the long term?

During a period lasting from 1 day to 21 months the histological picture of a dog's femur was studied after filling the marrow cavity with polymethylmethacrylate In order to distinguish between the effects of acrylic cement as such on the one hand and the effects of trauma and circulatory disturbances on the other hand, in control experiments the marrow space was emptied without subsequent filling with polymer

## EXPERIMENTAL ANIMALS AND TECHNIQUES

Dogs were chosen as experimental animals Apart from 12 mongrel dogs of various weights and unknown age 10 pure bred beagles 6 months old and weighing about 14 kg were used

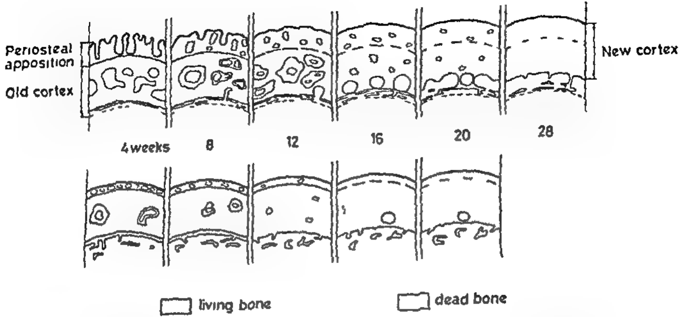


*Figure 1* Diagrammatic representation of the changes in the femoral cortex of beagles in the period 4–28 weeks after insertion of acrylic cement (top row). The bottom row illustrates the changes seen after the control operation

## RESULTS

### *Temperature measurements*

In eight dogs temperature measurements were performed by means of a needle thermocouple during and after insertion of the methacrylate On the outer surface of the cortex the maximum rise was 3 to 9° C it lasted about 30 minutes At the acrylate-bone interface temperature was measured through a thin hole drilled in the cortex An increase in temperature to 58° C was observed, i e a rise of 24° C This rise lasted about 25 minutes The thickness of the cortex was 1 8 to 2 5 mm

A single measurement carried out in a waterbath on an isolated dog femur filled with methacrylate showed a rise in temperature to 60° C

These data strongly suggest that the insertion of methacrylate leads to irreversible damage to cellular and intracellular proteins

### *The microscopy of bone changes*

As mentioned in the section Experimental Animals and Techniques, only a limited number of pure-bred beagles were available Therefore, mongrel dogs had to be used for a number of the experiments (Table 1) The beagles were used for a continuous series of experiments, viz for the stages 4 to 28 weeks Thus, the observations to be described were made in two series of experiments

Series I 4 to 28 weeks, a continuous series performed on beagles
Series II early stages (24 hours and 2 weeks) and late stages (10 to 21 months), these experiments were performed on dogs of various breeds and ages

The descriptions are based on both histological sections and microradiographs

### *Series I 4 28 weeks*

Three areas can be distinguished where alterations were seen 1) the space between the implant and the *cortex*, 2) *the cortex*, 3) the periosteum In this section changes observed in pure-bred beagles, over the period from 4 to 28 weeks are described The changes are presented schematically in Figure 1

Four weeks after the operation the cortical bone was dead, as shown by the fact that the osteocyte lacunae were empty They contained resorption cavities as a result of wide spread osteoclastic activity (Figure 2) Between the implant and the cortex there was a connective tissue


2
3
4
5

layer about 50 μ thick in which small islands of newly-formed bone were seen, the islands were surrounded by active osteoblasts. Against the inner aspect of the cortex a thin layer of immature bone was deposited. In contact with the implant (foreign body) giant cells were seen occasionally. At the periosteal side of the cortex a broad fringe of immature bone had formed, consisting of radially orientated trabeculae.

*Mention should be made here that the following criteria were applied to distinguish immature bone*: an irregular non-lamellar structure, large and irregular osteocyte lacunae, stronger P.A.S.-reactivity and in microradiographs, a greater density of mineral in the matrix.

The appearance of the cortical bone during the following weeks underwent a number of developments, which in the outer part were quite different from the changes in the inner part. In the outer half, 8 weeks after operation, a definite formation of new, immature bone could be discerned. This process of replacement went on continuously, the formation of immature bone soon being superseded by the formation of mature lamellar bone arranged in Haversian systems. At 16 weeks the outer half of the cortex was completely *remodeled* to normal living Haversian bone.

In the inner half no new formation of bone was seen (Figure 3). The resorption cavities became larger and more numerous. Merging of cavities eventually resulted in the presence of one large concentric cavity at 28 weeks. The cavity was about 500 μ across and filled with bone marrow.

In the area between cortex and methacrylate the formation of bone, starting from the isolated islands seen at 4 weeks, continued in such a way that after 28 weeks a cylindric bone sheath had formed, 50–100 μ thick (Figures 4 & 5). This sheath was only separated from the

*Figure 2. Endosteal part of the necrotic femoral cortex 4 weeks after insertion of acrylic cement. 300 ×. Hematoxylin phloxin. Irregular profile as a consequence of osteoclasia.*

*Figure 3. Endosteal part of the necrotic femoral cortex 8 weeks after insertion of acrylic cement. 200 ×. Hematoxylin phloxin. Between the irregularly eroded bone surface and the (dissolved) acrylic cement a layer of connective tissue and some fluid is present.*

*Figure 4. Newly formed islands of bone around the cement 12 weeks after insertion. 250 ×. Hematoxylin phloxin.*

*Figure 5. The same as Figure 4. Between the cement and the islands of bone multinucleated giant cells are seen. 200 ×.*

methacrylate by a thin layer of connective tissue containing multinucleated giant cells

The thin layer of bone which was deposited against the inner surface of the cortex during the first weeks increased in width until about the 16th week, but subsequently was broken down as the inner half of the cortex gradually became resorbed As a consequence of the concurrent processes of breakdown and new formation the situation arose that the above-mentioned bone sheath came to border on the large cavity arising from the continuous resorption of the inner part of the cortex (Figures 7 & 8) The contact between the sheath and the remainder of the cortex was then all but lost Against the implant an almost continuous layer of multinucleated giant cells was present, separated from the bone sheath by a connective tissue layer of some tens of microns in thickness

The periosteal fringe of newly-formed bone became more compact by the deposition of lamellar bone Remodeling processes resulted in a completely lamellar structure (Figure 6), the osteons being completely integrated with those of the pre existing cortex 20 weeks after operation

In the control experiments, in which the bone marrow was removed but not replaced by methacrylate, the course of the alterations in the period 4–28 weeks showed only a few similarities with the processes observed after the insertion of methacrylate Bone necrosis remained limited to a few small areas in the inner cortex Consequently remodeling was almost absent and only a few small cavities remained Deposition of a layer of new bone at the endosteal side took place to the same extent as seen after methacrylate insertion This layer, however, was integrated into the cortex without formation of the characteristic concentric cavity Periosteal bone formation was restricted to a layer the thickness of which was only about one fourth of the corre-

*Figure 6 The femoral cortex 16 weeks after the insertion of acrylic cement An extensive apposition of bone on the periosteal side has taken place 25 × Alcian blue—P A S staining*

*Figure 7 The femoral cortex [illegible] weeks after insertion of cement An extensive formation of cavities in the inner cortex as well as the deposition of a bone sleeve around the methacrylate is observed 25 × Alcian blue—P.A.S staining*

*Figure 8 The same as Figure 7 Detail of the bone sleeve Between the bone and the acrylic cement a multinucleated giant cell is seen 300 ×*

*Figure 9 Site of contact between connective tissue and bone with acrylic cement (dissolved during preparation) after 21 months The combined surface of the two tissues consists of serried concavities Hematoxylin phloxin 300 ×*

cavity was in most cases also enlarged even though to a smaller extent than the outer diameter. This points to a definite periosteal apposition and an (even if less extensive) endosteal breakdown. Histologically it was not possible to delimit new formation from the remodeled "old" cortex.

In six out of the eight dogs the histological pictures were in accordance with the development in the period 4–28 weeks observed in beagles: a circular bone sheath had formed which had lost contact with the inner aspect of the cortex. In three out of these six animals the sheath was complete, in the other three only isolated islands of bone were present. In all eight animals remains of necrotic bone were seen in the cortex, signs of remodeling and the formation of cavities were also observed. Multinucleated giant cells with a strongly vacuolated cytoplasm were present in all eight dogs in the 10–21 months series. These cells were always lying in close contact with the acrylic cement, i.e. inside the connective tissue layer surrounding the cement. Also in close contact with the polymer, eosinophilic, amorphous material was seen, probably representing accumulations of a protein-rich exudate. Frequently, both giant cells and exudate showed strings of convex indentations (Figure 9), a configuration which points to a typical shape of the surface of the (dissolved) methacrylate, consisting of sphere segments (Charnley 1970). This phenomenon was also seen in beagles 20 weeks after the operation. In the animals killed after 21 months the same profile, consisting of convexities, was seen in several places at the bone surface in direct contact with the methacrylate. This points to a direct contact between bone and cement. In some places the convexities in the tissue surface, alternately consisting of giant cells and bone, formed a sort of continuous garland.

## DISCUSSION

A number of the changes described in this paper have been reported in the literature. Necrosis of a part of the cortex in implantation experiments has been mentioned by a number of authors (inter al. Wiltse et al. 1957, Rietz 1968, Slooff 1970). Necrosis after the insertion of acrylic cement in man has been described by Charnley (1971).

Periosteal bone formation in man after the insertion of an intramedullary nail was seen by Küntscher as early as 1941. Periosteal bone apposition under experimental conditions was seen by inter al. Trueta & Cavadias (1955) and by Danckwardt-Lillieström et al. (1970). The

sponding layer around the femurs on which the complete operation had been performed

*Series II 24 hours–2 weeks and 10–21 months*

The early stages (24 h–2 weeks) and the later stages (10–21 months) had to be studied in *mongrel dogs because pure-bred beagles* were not available

After 24 h there were a few small hemorrhages None of the alterations described above were seen

After 2 weeks a small scale osteoclasia was apparent at the inner *surface of the cortex On the eroded surface osteoblasts* had in a few places started to deposit the new bone seen in the stages from 4 weeks onward Between the cortex and the methacrylate a thin layer of connective tissue was seen containing a few young thin bone trabeculae

The osteocytes in the cortex showed signs of degeneration Both from *the outside and from the inside incipient resorption* was observed in the form of small penetrating cavities At the periosteal aspect there was a 400 $\mu$ thick ring of newly formed bone consisting of radial trabeculae of immature bone, each trabecula surrounded by active osteoblasts

*Two weeks after the control operation the most important feature* was the beginning erosion of the inner surface of the cortex by osteoclasts, followed by the deposition of a rather broad layer of young bone The osteocytes in the cortex were alive Periosteally, a layer of new bone had formed the thickness of which was only 1/10 to 1/5 of that *after the insertion of methacrylate*

These pictures from the first weeks agree with those of the period between 4 and 28 weeks Thus, in the early phase it seems of minor importance that mongrel dogs had to be used instead of beagles

Experiments dealing with the later stages (10–21 months) and per*formed on mongrel dogs* are of limited value The results varied to such an extent that a chronological sequence of the stages was not clearly reflected in the microscopic pictures It is highly probable that this variation is due to the heterogeneity of the dogs as regards *breed* and age

Even so, a number of observations could be made on the animals in this group, yielding a picture broadly in agreement with the course of events observed in the beagles in series I (4–28 weeks) The outer shaft diameter had increased *by 1–3 mm The cross section* of the marrow

The concavities seen at the inner surface of the bone sleeve 21 months after the operation, the effect of a close contact with the methacrylate, have not previously been described either The bone substance of the sleeve seems to have formed in a normal intramembranous fashion Metaplasia of fibrous cartilage into bone as described by Charnley (1970) was not seen

It seems probable that the formation of the bone sheath around the inserted acrylic cement is somehow related to a continuous stimulus caused by weak mechanical forces The sheath is formed in proportion as the cortex loses its contact with the implant by progressive necrosis The fixation of the implant tends to deteriorate by bone necrosis, but in a way this function is taken over by the bone sheath

Although the circumstances of the experiments described here differ from those of patients with total hip replacement arthroplasty, some features suggest that a similar reaction pattern is found in man The relevant data are given in the aforementioned papers by Künscher (1941), Collins (1953, 1954), Thompson (1954) and Willert (1972) and in a study by Lindwer (1972) Such a similarity would mean that the fixation of the total replacement arthroplasty goes through a critical phase namely during the period when resorption and remodeling of necrotic bone is taking place but before a supporting bone case has formed The practical question should be asked us to whether during this period loading of the prosthesis should not be limited as much as possible Taking account of these considerations it seems advisable not to mobilize patients at too early a stage and to refrain from letting the patient walk without crutches after only a few monhs

## SUMMARY

Using dogs as experimental animals, polymerizing methylmethacrylate was inserted into the marrow cavity of the femur The influence on bone over a period of 21 months was studied by means of histological techniques and microradiography To distinguish the effect of the methacrylate proper from the circulatory disturbance resulting from the operation control experiments were performed in which the marrow cavity was emptied, but no acrylic cement was inserted

Polymerization of the methacrylate in vivo resulted in a local rise in temperature to about 58° C

In the femurs containing the acrylic cement a consistent picture developed consisting of al necrosis and removal of the central part of

latter authors made it seem plausible that necrosis of the cortex is largely due to the disturbance of the marrow circulation If care were taken to prevent an increase in intramedullary pressure during the insertion of a foreign body, bone necrosis remained restricted to a few small areas It could be shown that when intramedullary pressure in increased fatty marrow were pressed into the Haversian canals, there resulted a massive blocking of the blood vessels

In the experiments described in this paper an extensive cortical necrosis was seen Since necrosis in the control experiments was very limited and precautions were taken to prevent an increase in intra medullary pressure it can be concluded that the extensive cortical ne crosis seen after insertion of cement was only to a minor degree due to the trauma of the operation or to disturbance of the circulation Corti cal necrosis is therefore largely attributable to unfavorable factors in connection with the insertion of methacrylate viz the rise in tempera ture, and the leakage of monomer and other components

The question as to what extent long term chemical effects play a role cannot be answered with certainty The presence of chemical agents derived from the cement seems likely, judged from the occur rence of multinucleated giant cells with a vacuolated cytoplasm after 8 weeks Multinucleated giant cells in direct contact with the acrylic cement were also seen by Debrunner (1953) and by Charnley (1970) The presence of this type of cells points to the liberating of chemical components which can be resorbed by phagocytic elements (Mittel meyer & Singer 1956)

A fluid layer around the implant, as seen in the present investigation, is also described by Contzen et al (1967) around polymers implanted in soft tissue Possibly the occurrence of exudate also has to be looked upon as a sign of chemical irritation The formation of connective tis-sue around various types of implants, *inter al* bone, has frequently been described (Slais 1959, Rietz 1968)

A bone sheath formed around an implant has also been described Trueta & Cavadias (1955) and Rietz (1968) have observed such a structure around metal nails inserted in the bone in experimental ani mals Collins (1953, 1954) and Thompson (1954) observed it around metal implants in man Around implanted acrylic cement in human bone, Willert (1972) observed a rearrangement of bone trabeculae in such a way that new trabeculae had formed parallel to the surface A tight-fitting bone sleeve around acrylic cement, as seen in the present study, has not previously been described to the authors' knowledge

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*Key words* acrylic cement, bone remodeling, total hip replacement

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the cortex and b) apposition of a thick layer of bone on the outer surface of the cortex, c) deposition of a cylindrical bone sleeve in contact with the methacrylate In the control experiments only a minimal resorption at the inside surface of the cortex and the deposition of a thin layer of bone at the outside of the cortex were observed

It is concluded *inter al* that circulatory disturbance contributes only slightly to the total reaction of bone to the insertion of methacrylate

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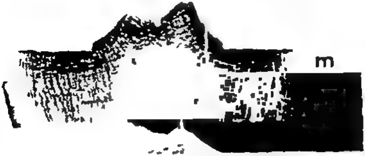


*Figure 1 Radiograph of a [illegible] mm thick slice from normal tibial condyles (m = medial) The demarcated zone was used for biochemical assay*

based on cartilage destruction osteophytes subchondral cysts and sclerosis The cases could be classified as grades II and III according to the classification suggested by Collins (1949) The ailment which prevailed for individuals from which specimens were taken is presented in Table 1 All patients had been fully active until 1–3 days before death

*Rheumatoid arthritis*

Specimens were obtained from 12 individuals with an age range of 53–86 years (Figure 2) All were classified as classical rheumatoid arthritis according to the criteria of the American Rheumatism Association (1958) Macroscopically as well as microscopically the changes matched those seen in the osteoarthritis cases very well Four of the twelve subjects had received general steroid treatment for various periods prior to the time at which the specimen was taken (In the previous study

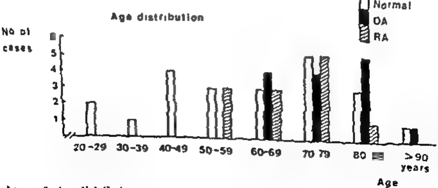


*Figure 2 Age distribution of material used for biochemical analysis of subchondral tibial bone in the normal state in osteoarthritis (OA) and in rheumatoid arthritis (RA)*

Acta orthop scand 46 672 684 1975

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# A BIOCHEMICAL ANALYSIS OF SUBCHONDRAL BONE OF THE MEDIAL TIBIAL CONDYLE IN THE NORMAL STATE AND IN OSTEOARTHRITIS AND RHEUMATOID ARTHRITIS

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Accepted 2 1 75

It has been shown in a previous study (Lereim et al 1974) that the hardness of subchondral trabecular bone of the medial tibial condyles increases with increasing age in normal individuals irrespective of sex In patients with osteoarthritis and rheumatoid arthritis the hardness however, was significantly lower than in the normal group There was no significant difference between osteoarthritis and rheumatoid arthritis

The present study concerns a biochemical analysis of subchondral trabecular bone in the medial tibial condyle with special reference to the density of the bone samples and their content of collagen, calcium phosphorus and magnesium

## MATERIAL

The specimens for this biochemical analysis were identical to those (Figure 1) used in the mechanical study previously reported (Lereim et al 1974) All specimens were taken from the medial condyle of the tibia and were obtained at autopsy after amputations or during reconstructive surgery

*Normal*

Specimens were obtained from 22 deceased individuals with an age range of 20–90 years (Figure 2) Radiology and naked eye observations verified the normal structure of the bone The causes of death are seen in Table 1 All individuals had been fully active until 0–2 days before death

*Osteoarthritis*

Specimens were obtained from 14 individuals with an age range of 62 91 years (Figure 2) The diagnosis was verified by radiology and naked eye observation

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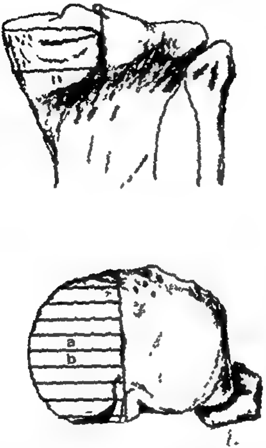


*Figure 3* *Schematic representation of the tibial condyles to demonstrate the sections used from the medial condyle for various analyses The biochemical analysis was carried out on bone from the weightbearing area here marked a and b*

sealing the vials the samples were hydrolysed at 125°C for 18 hours. The hydrolysates were divided into appropriate samples for the different analyses

*Collagen*

Collagen was determined according to the method of Firschein & Shill (1966) The part of the hydrolysate used for the estimation of collagen was filtered through a fine porosity fitted glass disc (Pyrex G3) and the content of hydroxyproline was

*Table 1 Medical procedure carried out on individuals from whom bone samples from the medial tibial condyle have been obtained for biochemical analysis*

| Autopsy | | Normal | OA | RA |
|---|---|---|---|---|
| | 1 Cardiovascular disease | 8 | 6 | 6 |
| | 2 Cerebral haemorrage | 3 | 1 | |
| | 3 Cancer not affecting the skeletal system | 8 | | |
| | 4 Various diseases | 3 | 1 | |
| Femoral amputation | | | 6 | 1 |
| Reconstructive surgery | | | | 5 |
| Total | | 22 | 14 | 12 |

on testing of hardness (Lereim et al 1974) it was shown that steroids had no influence on the hardness The chemical composition of the subchondral bone of steroid and non steroid treated patients is commented upon on page 683 The source of the specimens is seen in Table 1 All individuals had been active until 3–4 days before death

## METHODS

Immediately after removal the specimens were frozen and kept at $-20°$ C. After the Brinell hardness testing at room temperature the specimens were once more frozen to $-20°$ C (Lereim et al 1974) The frozen specimens were then cut into 5 mm thick slices (Figure 3) which were totally freed from soft tissues and cartilage For biochemical analysis slices (a or b in Figure 3) from the weight bearing area were used

### Volume and weight

The specimens were weighed by attaching them to a surgical needle on a fine wire hanging on a balance Thereafter they were weighed submerged in distilled water while still suspended from the balance as described After the specimens had been weighed in water they were weighed in air again These procedures were undertaken at room temperature (about 22° C) The weight of the bone piece in air returned to the original wet weight after submerging in water The weight of the water displaced by the bone sample gave the volume of the actual sample at room temperature and the density could be calculated as weight per volume

The specimens were defatted in two changes of acetone over a period of 48 hours and in two changes of ether for another 48 hours After this the bone pieces were dried in air at 50° C to constant weight Then the weight of the dry fat free samples was recorded

Each sample was placed in hydrolysis vials and 10 ml [illegible] N HCL was added After

*Table 2 Density of subchondral tibial bone Mean values in different age groups of normal individuals and those with osteoarthritis (OA) or rheumatoid arthritis (RA)*

| Age | Normal | n | O A | n | R A | n |
|---|---|---|---|---|---|---|
| < [illegible] | 1.33 | (7) | | | | |
| 50—59 | 1 30 | (3) | – | | 1 39 | (3) |
| 60—69 | 1 25 | (3) | 1 22 | (4) | 1 29 | (3) |
| 70—79 | 1 29 | (5) | 1 18 | (4) | 1 27 | (5) |
| 80—89 | 1 20 | (3) | 1 24 | (5) | 1.37 | (1) |
| > 90 | 1 29 | (1) | 1 36 | (1) | – | |
| Mean > [illegible] | 1 27 ± 0 05 | | 1 23 ± 0 07 | | 1.31 ± 0 11 | |
| Total normal | 1 29 ± 0 06 | | | | | |

### *Chemical determination*

The results of the chemical determinations are presented as percentage of dry fat free bone and mg/ml wet bone Differences between the groups (normal, osteoarthritis and rheumatoid arthritis) have been calculated with the above mentioned units Specimens in normal individuals below the age of 56 were excluded as corresponding values for the pathological groups were not obtained The change with age has been calculated for the normal state in mg/ml. Calculations for possible changes with increasing ages in the pathological groups have not been done

*Table 3 Collagen in subchondral tibial bone Mean values in the normal state in osteoarthritis (OA) and in rheumatoid arthritis (RA) expressed in percentage of dry fat free bone weight (%) and mg/ml wet bone*

| Age | Normal | | | O A | | | R.A | | |
|---|---|---|---|---|---|---|---|---|---|
| | % | n | mg/ml | % | n | mg/ml | % | n | mg/ml |
| < 50 | 23.28 | (7) | 133 60 | | | | | | |
| 50 59 | 23 91 | (3) | 117.83 | – | | – | 26.37 | (3) | 180 63 |
| 60—69 | 23 74 | (3) | 112.23 | 23 66 | (4) | 94.80 | 23 40 | (3) | 119 03 |
| 70—79 | 23 14 | (5) | 119.20 | 23 75 | (4) | 84 97 | 23 07 | (5) | 115.38 |
| 80—89 | 23.33 | (3) | 93.20 | 23 53 | (5) | 103.24 | 20 91 | (1) | 148 8 |
| > 90 | 24 89 | (1) | 149.20 | 24 58 | (1) | 141.2 | – | | – |
| Mean > 56 | 24 ± 1.3 | | 115 ± 17 | 24 ± 1 4 | | 100 ± 31 | 24 ± 2 2 | | 133 ± 53 |
| Total normal | 24 ± 1 1 | | 121 ± 19 | | | | | | |

measured. The content of collagen was calculated assuming that 14.5 per cent of the collagen was hydroxyproline (McLean & Urist 1968).

### *Calcium – Phosphorus – Magnesium*

Part of the hydrolysate was diluted 1 : 100 with distilled water. Calcium was determined by the SMA 12/60 System Calcium method, which is a modification (Gitelman 1967) of the method of Kessler & Wolfman (1964). Phosphorus was determined by the SMA 12/60 System Inorganic Phosphate method, which is based on the formation of phosphomolybdic acid (Kraml 1966).

For the magnesium determination part of the hydrolysate was diluted 1 : 10 with distilled water. This mixture was diluted 1 : 26 with 2 per cent lanthanum chloride and analysed in a Unicam SP 90 atomic absorptions spectrophotometer. Day to day variation coefficients were: Ca 1.9 per cent, P 3.7 per cent, and Mg 5.1 per cent.

### *Statistical analysis*

For statistical analysis Student's *t* test was used as well as chi square analysis (Ulf Runze B. A.).

## RESULTS

### *Density*

The density (w/v) of the individual specimens is shown in Figure 4. A presentation of mean values is made in Table 2. In the normal group there was a decrease in density with advancing age ($P < 0.05$). Over the age of 54 there was no significant difference between the three groups. In the entire material there was a tendency for a decrease in density with advancing age ($0.05 < P < 0.10$). The age group 70–79 years had the lowest density.

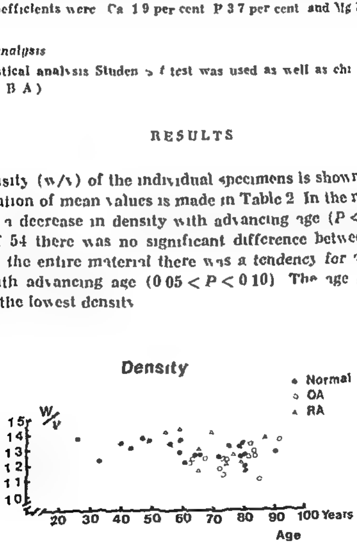


*Figure 4.* Density in weight per volume of subchondral bone from the medial tibial condyle in the normal state, in osteoarthritis and rheumatoid arthritis related to age.

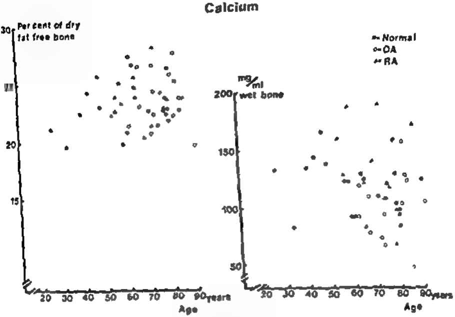


*Figure 6 Individual calcium determinations in subchondral bone from the medial tibial condyle in the normal state, in osteoarthritis and in rheumatoid arthritis, related to age*

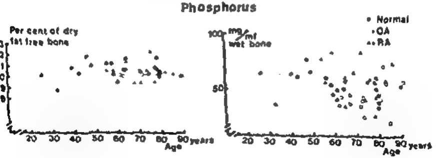


*Figure 7 Individual phosphorus determinations in subchondral bone from the medial tibial condyle in the normal state in osteoarthritis and in rheumatoid arthritis, related to age*

the mean value of the normal bone was found to be between those of the other two groups (Figure 7, Table 5).

The content per volume of tissue decreased significantly with age in the normal group ($P < 0.05$)

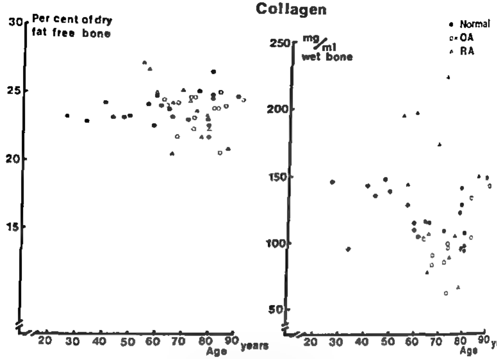


*Figure 5 Individual collagen determinations in subchondral bone from the medial tibial condyle in the normal state, in osteoarthritis and in rheumatoid arthritis related to age*

## *Collagen*

There was no significant difference between the three groups (Figure 5, Table 3) However, there was a tendency for a difference between osteoarthritis and rheumatoid arthritis ($0{\cdot}05 < P < 0{\cdot}10$), the highest mean value being found in rheumatoid arthritis

The collagen content remained unchanged with increasing age

## *Calcium*

The calcium content per volume of tissue was significantly higher in rheumatoid arthritis than in osteoarthritis ($P < 0{\cdot}05$) while the mean value of the normal bone was found to be between those of the pathological groups (Figure 6, Table 4)

The calcium content in the normal state was constant with increasing age

## *Phosphorus*

The content of phosphorus per volume of tissue was significantly higher in rheumatoid arthritis than in osteoarthritis ($P < 0{\cdot}05$) while

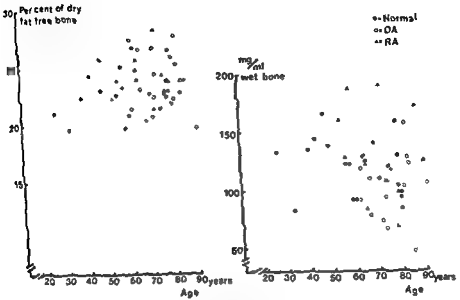


*Figure 6 Individual calcium determinations in subchondral bone from the medial tibial condyle in the normal state, in osteoarthritis and in rheumatoid arthritis, related to age*


*Figure 7 Individual phosphorus determinations in subchondral bone from the medial tibial condyle in the normal state, in osteoarthritis and in rheumatoid arthritis, related to age*

the mean value of the normal bone was found to be between those of the other two groups (Figure 7, Table 5).

The content per volume of tissue decreased significantly with age in the normal group ($P < 0.05$).

*Table 4 Calcium content of subchondral tibial bone Mean values in the normal state, in osteoarthritis (OA) and in rheumatoid arthritis (RA) expressed in percentage of dry fat free bone weight (%) and mg/ml wet bone*

| Age | Normal | | | O A | | | R A | | |
|---|---|---|---|---|---|---|---|---|---|
| | % | n | mg/ml | % | n | mg/ml | % | n | mg ml |
| < 50 | 23 02 | (7) | 135 3 | | | | | | |
| 50—59 | 22 48 | (3) | 111 10 | – | | – | 23 23 | (3) | 157 46 |
| 60—69 | 24 10 | (3) | 114 63 | 24 57 | (4) | 98 82 | 23 29 | (3) | 114 76 |
| 70—79 | 22 66 | (5) | 123 34 | 23 55 | (4) | 84 40 | 24 06 | (5) | 114 78 |
| 80—89 | 23 73 | (3) | 90 96 | 24 95 | (5) | 110 27 | 23 88 | (1) | 169 90 |
| > 90 | 22 78 | (1) | 122 5 | 19 68 | (1) | 113 00 | – | | – |
| Mean > 56 | 23 ± 1 9 | | 112 ± 20 | 24 ± 2 6 | | 100 ± 28 | 24 ± 2 0 | | 130 ± 40 |
| Total normal | 23 ± 2 0 | | 118 ± 23 | | | | | | |

*Table 5 Phosphorus content of subchondral tibial bone Mean values in the normal state in osteoarthritis (OA) and in rheumatoid arthritis (RA) expressed in percentage of dry fat free bone weight (%) and mg/ml wet bone*

| Age | Normal | | | O A | | | R A | | |
|---|---|---|---|---|---|---|---|---|---|
| | % | n | mg/ml | % | n | mg/ml | % | n | mg/ml |
| < 50 | 10 62 | (7) | 62 33 | | | | | | |
| 50—59 | 11 01 | (3) | 54 24 | – | | – | 10 73 | (3) | 73 08 |
| 60—69 | 10 79 | (3) | 51 28 | 10 78 | (4) | 41 19 | 10 70 | (3) | 53 4[illegible] |
| 70—79 | 10 94 | (5) | 56 06 | 10 30 | (4) | 37 09 | 10 51 | (5) | 50 [illegible] |
| 80—89 | 10 41 | (3) | 40 40 | 10 36 | (5) | 49 75 | 10 36 | (1) | 73 72 |
| > 90 | 10 19 | (1) | 54 80 | 10 19 | (1) | 58 56 | – | | – |
| Mean > 56 | 10 8 ± 0 6 | | 52 ± 4 | 10 5 ± 0 7 | | 44 ± 14 | 10 6 ± 0 9 | | 59 ± 19 |
| Total normal | 10 7 ± 0 7 | | 55 ± 9 | | | | | | |

### *Ca/P-ratio*

There was no difference between rheumatoid arthritis and the normal state whereas there was a tendency for higher values in osteo arthritis ($0\,05 < P < 0\,10$) (Figure 8, Table 6) The mean value for the normal group was 2 14 and did not change with advancing age

### *Magnesium*

There was no difference between the three groups (Figure 9 Table 7) In the normal group there was a decrease in magnesium per volume of tissue with advancing age ($P < 0\,05$)

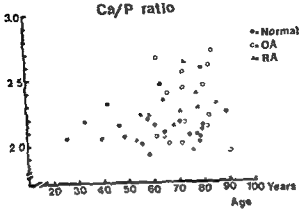


*Figure 8 Individual Ca/P ratio in subchondral bone from the medial tibial condyle in the normal state, in osteoarthritis and in rheumatoid arthritis, related to age*

*Table 6 Ca/P ratio in subchondral tibial bone Mean values in the normal state, in osteoarthritis (OA) and in rheumatoid arthritis (RA) expressed in percentage of dry fat free bone weight (%) and mg/ml wet bone.*

| Age | Normal | | O A | | R A. | |
|---|---|---|---|---|---|---|
| | mg/ml | n | mg/ml | n | mg/ml | n |
| < 50 | 2.17 | (7) | | | | |
| 50—59 | 2.04 | (3) | – | | 2.16 | (3) |
| 60—69 | 2.23 | (3) | 2.27 | (4) | 2.17 | (3) |
| 70—79 | 2.07 | (5) | 2.28 | (4) | 2.28 | (5) |
| 80—89 | 2.27 | (3) | 2.40 | (5) | 2.01 | (1) |
| > 90 | 2.23 | (1) | 1.93 | (1) | – | |
| Mean > 56 | 2.15 ± 0.17 | | 2.31 ± 0.19 | | 2.24 ± 0.18 | |
| Total normal | 2.14 ± 0.16 | | | | | |

## COMMENTS

The reasons for expressing the chemical results both as percentage of dry fat free bone weight and as mg/ml wet bone volume was that this allowed a comparison of the results with those of earlier reports In these, the percentage of dry fat free bone weight as the basic unit is often used However, Robinson & Elliot (1957) and especially Strandh & Norlén (1965) showed that in studies of bone atrophy the results would not disclose any major differences when calculations were made on a weight basis Greater confidence in results for com-

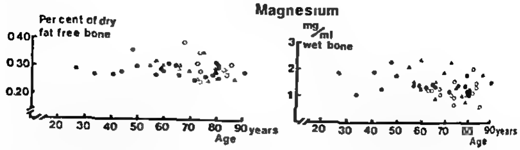


*Figure [illegible] Individual magnesium determinations in subchondral bone from the medial tibial condyle in the normal state, in osteoarthritis and in rheumatoid arthritis, related to age*

*Table 7 Magnesium content of subchondral tibial bone Mean values in the normal state, in osteoarthritis (OA) and in rheumatoid arthritis (RA) expressed in percentage of dry fat free bone weight (%) and mg/ml wet bone*

| Age | Normal | | | O A | | | R A | | |
|---|---|---|---|---|---|---|---|---|---|
| | % | n | mg/ml | % | n | mg/ml | % | n | mg/ml |
| < [illegible] | 0.30 | (7) | 1.75 | | | | | | |
| 50—59 | 0.28 | (3) | 1.39 | – | | – | 0.31 | (3) | 2.00 |
| 60—69 | 0.29 | (3) | 1.39 | 0.30 | (4) | 1.22 | 0.29 | (3) | 1.49 |
| 70—79 | 0.27 | (5) | 1.42 | 0.29 | (4) | 1.07 | 0.27 | (5) | 1.30 |
| 80—89 | 0.29 | (3) | 1.12 | 0.28 | (5) | 1.32 | 0.25 | (1) | 1.78 |
| > 90 | 0.28 | (1) | 1.51 | 0.27 | (1) | 1.56 | – | | – |
| Mean > 56 | 0.28 ± 0.02 | | 1.36 ± 0.19 | 0.29 ± 0.03 | | 1.24 ± 0.37 | 0.29 ± 0.03 | | 1.57 ± 0.5[illegible] |
| Total normal | 0.29 ± 0.02 | | 1.46 ± 0.32 | | | | | | |

parison could be obtained in recording mg/ml wet bone volume In this study the opinion of Strandh & Norlen (1965) was confirmed as the variations in the results were very small when calculated on the weight basis, whereas the calculations on the volume basis revealed greater variation We found this more suitable as a means of illustrating the age influence and the differences between subchondral bone from individuals with normal and diseased knee joints It became evident that this procedure was more appropriate when comparison was made with the results obtained at a determination of the physical properties and the chemical composition of bone as presented by Romanus in 1974 The background for our study was to correlate, if possible, the results of a hardness testing of subchondral bone with the chemical analysis For this reason it was found more acceptable to calculate the

influence of age on the different chemical components, as well as the difference between the various groups, on the basis of volume rather than on percentage of dry fat free bone weight

In this investigation it was shown that the difference in the chemical content of bone between the three different groups (normal, osteoarthritis and rheumatoid arthritis) and the influence of age were rather small (In our small material we found no difference in chemical composition of bone from steroid and non steroid treated patients with rheumatoid arthritis) This can only in part suggest an explanation for the possibility of the chemical composition serving as a background for the great differences in hardness in the same subchondral bone material as reported by Lereim et al (1974) Therefore, material identical to that used for this investigation will be further analysed by histologic and radiologic means in order to throw more light on the factors behind the difference in hardness of subchondral bone in the different groups

## SUMMARY

A chemical analysis has been carried out on specimens from the subchondral weightbearing area of the medial tibial condyle from 22 normal individuals 14 individuals with osteoarthritis and 12 individuals with rheumatoid arthritis In the normal group there was a decrease in density with advancing age Over the age of 50 there was no significant difference between the groups

The content of collagen, calcium, phosphorus and *magnesium* in each bone specimen was calculated When expressed in per cent of dry fat free bone there was no significant difference between the three groups When calculations were made on the basis of content per volume tissue wet bone some differences were found There was a tendency for a higher content of collagen in rheumatoid bone than in normal and osteoarthritic bone The content of calcium was significantly higher in rheumatoid arthritis than in osteoarthritis, the same result was found in the analysis of phosphorus In the normal group there was a decrease in phosphorus content with advancing age, this was also seen in the magnesium analysis

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*Key words* rheumatoid arthritis osteoarthritis normal bone bone chemistry *collagen*

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Acta orthop scand 46, 685-691 1975

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# CHONDROMALACIA OF THE PATELLA

## *Physical Signs in Relation to Operative Findings*

J Stolgård

Accepted 2 i 75

Cartilaginous changes on the patella are, according to post-mortem findings (Heine 1926, Øwre 1936) and findings at operation (Silfverskiold 1938, Wiles et al 1956), so common that one-third to one-half of the adult population has macroscopic changes on their patellae

The object of this study was to investigate the relationship between the supposed characteristic physical signs of these cartilaginous changes named chondromalacia patellae and the macroscopic changes seen at operation

### MATERIAL AND METHODS

The material comprised 100 patients, 70 males and 30 females, treated for suspected intra articular disease of the knee, most often sequelae to trauma Patients with rheumatoid arthritis severe osteoarthritic changes sequelae to infections, and tumours in the knee joint were not included in this study The youngest patient was 14 and the oldest 59 The age distribution is presented in Table 1 52 cases were right sided and 48 left sided

The methods included a physical examination preoperatively and peroperatively of the affected knee joint

The *preoperative* examination was performed by one or more surgeons at the primary consultation and by the author on the day before the operation and included an examination of the limb and the knee joint as a whole, but the greatest importance was attached to palpation of the patellar region The main findings here were divided into the following four groups

#### *Retropatellar crepitation*

This examination was carried out on the extended relaxed knee by pressing the patella down towards the patellar surface of the femur and moving it up and down and sidewards As the changes are usually situated on the patella, any crepitation was ascribed to the patella although the changes may be situated on the femur To simplify the assessment of the results the crepitation was not graded in quantity or in quality

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good view of the posterior surface of the patella Sometimes it was supplemented with a lateral incision

## FINDINGS

### Physical Signs

*The author's findings* Retropatellar crepitation was present in 52 cases A subjective sensation in the form of pain on grating the patella occurred in 29 cases discomfort in 10 a total of 39 positive cases Tenderness on palpating the patella was found in 14 cases medially, in 15 cases medially as well as laterally, and in one case laterally only A total of 30 patients were recorded as having this sign Infrapatellar tenderness with or without swelling of the infrapatellar tissue was found in nine cases

Effusion in the joint was observed in 18 cases capsular swelling in five capsular tenderness in four Direct tenderness of the joint line and/or pain on rotation occurred medially and/or laterally in 72 and 49 cases respectively Quadriceps function was assessed by measuring the circumference of the femur 15 cm proximal to the patella compared with the normal leg In 53 cases there was no difference in 38 cases there was atrophy of less than 2 cm and in nine cases atrophy of 2 4 cm

*The other examiner's findings* In the records the findings positive or negative of the four main symptoms concerning the patella were not always mentioned Of the 57 cases examined for retropatellar crepitation 35 showed a positive sign Assessment of pain in this examination had been made in 54 cases and was positive in 27 Tenderness on palpation of the patella had been assessed in only 20 cases and was positive in 11

### Operative Findings

The report of these findings will be concentrated on the patella and its surroundings Cartilaginous changes were present on the patella in 50 cases The medial facet was more often involved than the lateral one Changes on both facets found in 23 cases were often more extensive comprising in nine cases the entire area of both articular facets In five cases only a small area was involved localized on the extreme medial aspect and covered by a synovial fold Examination for crepitation during the operation failed to establish contact between this area and the patellar surface of the femur

The most common change in the cartilage was oedema giving a greyish

*Table 1 Distribution according to sex and age of the patient, of patellae with cartilaginous changes among 100 patients operated unilaterally for intra articular diseases The area involved on the medial (M) and lateral (L) facet is given in square millimeters (mm²)*

| Sex | Age (years) | Number of patients | Number of patellae with changes | Area with cartilaginous changes | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | < 100 mm² | | 100–200 mm² | | > 200 mm² | |
| | | | | M | L | M | L | M | L |
| | 10–19 | 9 | 2 | 0 | 0 | 0 | 0 | 2 | 1 |
| | 20–29 | 22 | 9 | 5 | 1 | 1 | 0 | 3 | 1 |
| Male | 30–39 | 20 | 12 | 2 | 1 | 1 | 4 | 9 | 4 |
| | 40–49 | 13 | 8 | 2 | 0 | 2 | 1 | 4 | 2 |
| | 50–59 | 6 | 4 | 2 | 1 | 0 | 0 | 2 | 1 |
| | 10–19 | 6 | 1 | 0 | 0 | 1 | 0 | 0 | 0 |
| | 20–29 | 7 | 5 | 1 | 0 | 3 | 1 | 1 | 2 |
| Female | 30–39 | 10 | 4 | 0 | 0 | 0 | 0 | 3 | 2 |
| | 40–49 | 6 | 4 | 3 | 0 | 0 | 0 | 1 | 1 |
| | 50–59 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 |
| Total | | 100 | 50 | 15 | 3 | 8 | 6 | 26 | 15 |

### *Pain on grating the patella against the femur*

The examination was performed as described above and the patient s reaction was recorded The most common sensation was pain in other cases merely discomfort It was decided that no distinction should be made between the quality or quantity of the pain stating merely whether or not pain was present

### *Tenderness on palpation of the patella*

In some cases tenderness is elicited by grasping the patella In other cases the tenderness is produced by displacing the patella to the side at the same time palpating the joint surface or by pressing distally upon the upper pole while the patient keeps the quadriceps tense The site of tenderness on the patella was recorded but to simplify matters only whether or not tenderness was present was stated

### *Infrapatellar changes*

Tenderness of the infrapatellar tissue on both sides of the inferior patellar ligament on palpation was recorded and stated as being present or absent regardless of whether it occurred medially or laterally Examination for swelling of the infrapatellar tissue was carried out but proved to be too uncertain and was therefore not included among the findings

The *peroperative* examination was done at operation (performed by the author) in a bloodless field through a medial parapatellar incision This incision offers a

synovial fluid In another nine cases the fissures extended right down to the bone, denuding it in major or minor areas Cartilage changes were seen also in other parts of the joint, in eight affecting the patellar surface of the femur, invariably associated with changes on the patella In the femoro tibial joint changes were found on the femur in 10 cases and on the tibia in four

It was difficult to estimate the size of the infrapatellar pad of fat It was estimated as being hypertrophic in five cases (only one of which was in accordance with the preoperative findings) In 24 cases synovial changes were observed, 11 of these were combined with cartilage changes on the patella, in five with patellar as well as meniscal changes, in five cases with meniscal lesion only, and in two cases the diagnosis was traumatic synovitis In the cases exhibiting the cartilaginous changes it was particularly the synovial membrane around the patella which was affected In six instances X-rays had shown the patella to be bipartite in the upper lateral corner The junction between the two parts of the patella was visible at operation as a faint groove in the articular surface in three cases In one case the changes affected the small extra bone, in two cases the medial articular facet in the remaining three cases the cartilage was normal

The most common lesion was a torn meniscus, 56 medial, six lateral,

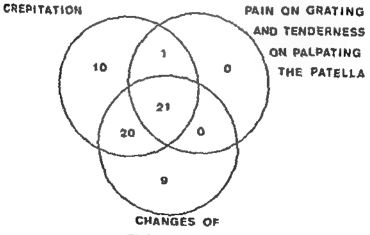


*Figure 3 Correlation of retropatellar crepitation pain on grating and tenderness on palpating the patella with cartilaginous changes on the patella among 100 patients with intra articular disorder*

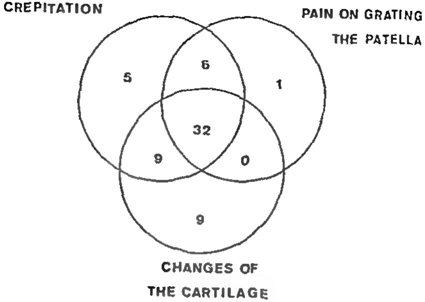


*Figure 1 Correlation of retropatellar crepitation and pain on grating the patella with cartilaginous changes on the patella among 100 patients with intra articular disorder*

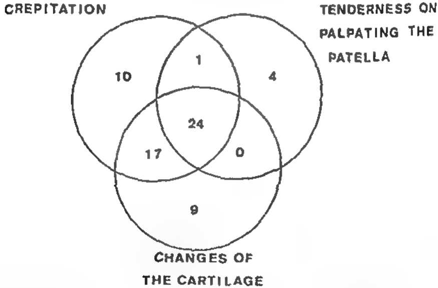


*Figure 2 Correlation of retropatellar crepitation and tenderness on palpating the patella with cartilaginous changes on the patella among 100 patients with intra articular disorder*

lustreless surface domed above the normal level and of a softer, more inelastic consistency This was observed in 46 out of the 50 cases Fissures were found in 42 cases Flakes still sticking to the surface had formed in 22, and in nine cases there were cartilaginous flakes in the

synovial fluid In another nine cases the fissures extended right down to the bone, denuding it in major or minor areas Cartilage changes were seen also in other parts of the joint, in eight affecting the patellar surface of the femur, invariably associated with changes on the patella In the femoro tibial joint changes were found on the femur in 10 cases and on the tibia in four

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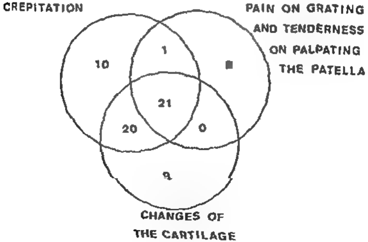


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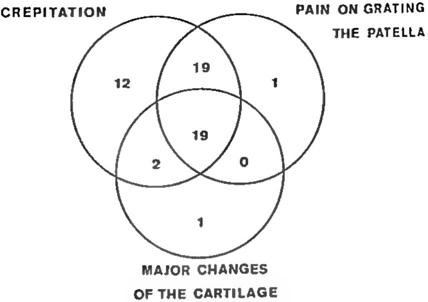


*Figure 4 Correlation of retropatellar crepitation and pain on grating the patella with major cartilaginous changes on the patella among 100 patients with intra articular disorder*

and two cases with injury to both menisci giving a total of 66 torn menisci Two patients had recurrent dislocation of the patella, one had osteochondritis dissecans on the femur, two had traumatic synovitis, whereas in one case no abnormality could be demonstrated Thus, the cartilaginous changes on the patella were the only abnormality in 28 cases, and in 22 cases they coincided with other intra articular changes

The relation between the clinical findings (crepitation, pain on grating and tenderness on palpation of the patella) and the cartilaginous changes is illustrated by Venn diagrams (Figures 1-4) In Figure 3 cases with both pain on grating and on palpation of the patella are related to crepitation and cartilaginous changes Figure 4 includes only the cases with severe changes of the cartilage The nine cases without any of the three main physical signs but with cartilaginous changes, had these rather small changes on the medial facet only and in five cases they were even in an extreme medial location Only in one case did the changes involve about one-third of the medial facet

Among the nine cases with infrapatellar tenderness six had cartilaginous changes In four of these cases the synovial membrane showed changes, in particular medially and inferior to the patella

The signs found by the other examiner were related to the operative

findings and to the author s findings Crepitation had been found in 35 cases, 24 had cartilage changes and of the latter, 23 had exhibited crepitation during the author s examination Pain on grating the patella was demonstrated in 27 cases, 17 were found to have cartilage changes and had pain when examined by the author Tenderness on palpation of the patella was demonstrated in 11 cases, eight of which showed cartilaginous changes and all eight complained of tenderness when examined by the author

Although the subjective symptoms were not included (mainly because of the difficulty in distinguishing them from symptoms due to other intra articular diseases), it may be stated that 16 patients had a history indicating chondromalacia of the patella, at operation all exhibited cartilaginous changes on the patella All 16 had crepitation, 11 had pain on grating and tenderness on palpation of the patella, and the remaining five had one of the two latter signs

## DISCUSSION

The present study confirms that cartilage changes on the patella are a common occurrence also when combined with other intra articular changes Among the physical signs retropatellar crepitation has been considered an important sign by all workers (Aleman 1928, Kulowski 1933, Hinricsson 1939, Bronitsky 1947, Cahen 1955) Budinger (1906) and Lawen (1925) pointed out that the final diagnosis could not be made until operation and others (Øwre 1936, Thiemeyer 1955, Wiles et al 1956) have submitted cases with cartilage changes, but without any preoperative crepitation Aleman (1928) and Karlsson (1940) both felt that they could distinguish between the quality and quantity of the crepitation the location and whether the changes were recent or longstanding Such a classification has not been used in this study, although it must be admitted that the quality and quantity of crepitation does vary from patient to patient Disregarding the five cases with cartilaginous changes localized extremely medially, outside the weight bearing surface, crepitation could be elicited in 41 out of 45 cases If only cases with more severe cartilage changes are included crepitation was absent in only one case On the other hand, this sign occurred in 11 cases without visible cartilage changes Thus, crepitation must be considered an important, but not pathognomonic sign of cartilaginous changes on the patella

Pain on grating the patella is considered by some authors as perhaps

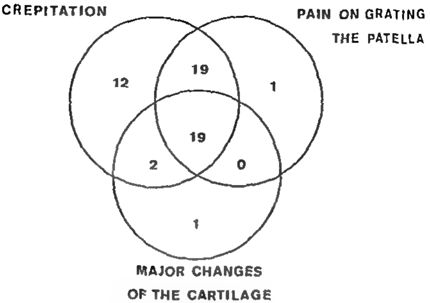


*Figure 4 Correlation of retropatellar crepitation and pain on grating the patella with major cartilaginous changes on the patella among 100 patients with intra articular disorder*

and two cases with injury to both menisci giving a total of 66 torn menisci Two patients had recurrent dislocation of the patella, one had osteochondritis dissecans on the femur, two had traumatic synovitis, whereas in one case no abnormality could be demonstrated Thus, the cartilaginous changes on the patella were the only abnormality in 28 cases, and in 22 cases they coincided with other intra-articular changes

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The signs found by the other examiner were related to the operative

## SUMMARY

Cartilaginous changes on the patella are common and were demonstrated in 50 out of 100 patients who underwent operation for intra-articular disease of the knee joint In order to clarify further the signs of this condition, the physical signs were related to the operative findings Retropatellar crepitation was present in most cases, but cannot be called pathognomonic Pain on grating and tenderness on palpation of the patella in fact occurred together only in cases with cartilaginous changes on the patella On the other hand, cartilaginous changes were found in several cases without such signs, a condition which perhaps should be interpreted as cartilaginous changes only, not as the symptom complex chondromalacia of the patella in which there ought to be a history of symptoms


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an even more definite sign (Bronitsky 1947, Cahen 1955, Thiemeyer 1955, Wiles et al 1956, Robinson & Darracott 1970) In this study it was found in 39 cases, and of these 32 showed cartilaginous changes Darracott & Vernon-Roberts (1971) demonstrated bony changes with only modest microscopic changes of the cartilage This might explain the pain elicited in seven cases with a macroscopically normal cartilage, where microscopic changes possibly could have decreased the ability of the cartilage to protect the underlying bone

Tenderness on palpation has been described using various methods Wiles et al (1956) and Robinson & Darracott (1970) stress the importance of being able to palpate the joint surface The former considered this sign, plus crepitation, to be diagnostic In the present investigation this tenderness was demonstrated in 29 cases 24 of which had cartilaginous changes As regards both pain-eliciting examinations, it is apparent that cartilaginous changes may be present in a fairly large number of cases without giving rise to these two clinical findings A possible explanation is that in these cases the cartilage changes have not given rise to a painful state with a history of patellar disease and are therefore not demonstrable by the two methods of examination This is to some extent confirmed by the 16 cases with a history of chondromalacia of the patella only All had retropatellar crepitation as well as one, and in most cases two, of the pain-eliciting signs

Infrapatellar swelling and tenderness were considered by Frund (1926), Aleman (1928), Karlsson (1940), Bronitsky (1947), and de Montmolin (1951) to be signs of synovitis caused by the cartilaginous changes In the present study infrapatellar swelling was recorded, but not included in the analysis, as it is difficult to assess Infrapatellar tenderness was demonstrated in nine cases only At operation six were found to have cartilaginous changes Therefore, these two signs were not attributed any major diagnostic importance

Other clinical signs were not related to the patellar changes, as other and presumably more important disorders were contributory However, chondromalacia of the patella may give rise to effusion, capsular swelling, and capsular tenderness, etc, and together with the three main signs they may round off the picture of this common disease However, a distinction should still be made between an asymptomatic change of the cartilage on the patella and the clinical symptom complex named chondromalacia of the patella, basing the diagnosis both upon the history and the physical signs

Acta orthop scand 46 695–699 1975

Princess Alexandra Hospital Harlow England

# CHONDROMALACIA AND THE UNSTABLE PATELLA

D J Dandy & H Poirier

Accepted 8 II 75

This paper reports a series of operations done for patella instability, in which the symptoms of chondromalacia patellae regressed without shaving or drilling of the articular cartilage

## MATERIAL AND METHOD

Fifty seven patients were operated upon and 47 (11 males and 36 females) were traced and examined Nine of the 47 had operations on both knees and two were operated on twice to make a total of [illegible] operations available for study

Symptoms began between the ages of 11 and 18 in 43 cases with a peak at the age of 13 girls were generally slightly younger at the onset of symptoms than boys The duration of symptoms before operation ranged between 6 months and 30 years with a mean of 4 years 4 months and the interval between operation and review ranged between 1 year and 5 years 9 months with a mean of 3 years 11 months

From the patient s history the stability of the patella was placed in one of three categories normal recurrent subluxation or recurrent complete dislocation The extensor mechanism was considered to be subluxing if the patient gave the typical account of the knee "giving way" without warning during walking or running some t mes followed by an effusion into the joint (Hughston 1968)

Tenderness of the soft tissues medial [illegible] the patella was a common finding and helped to distinguish the condition from a meniscus injury in which the tenderness is along the joint l ne Patients were said to have recurrent dislocation if their patella had dislocated completely more than once

Patients were cons dered to have chondromalacia patellae if in addition to the symptoms of dislocation or subluxation of the patella they complained of pain or d scomfort when climbing or descending stairs getting out of a chair or rising from a squatting position or of aching when the knee was straightened after being flexed for a long time as in a car or the theatre The pain could usually be reproduced by pressing the patella against the femur the undersurface of the patella being tender These symptoms were classed as mild severe or absent

A medial plication of the capsule was done to avoid growth changes if the apoph ysis of the tibial tubercle had not fused to the tibia (6 cases) A Goldthwaite operation (Goldthwa te 1904) was done in three patients who were keen athletes because it was less l kely to impair their performance than an extensive procedure requiring arthrotomy The t bial tubercle was transposed in 39 cases Hauser's oper

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*Key words* chondromalacia patellae osteoarthritis patella, knee joint femoro patellar joint

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Acta orthop scand 46, 695-699, 1975

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Symptoms began between the ages of 11 and 18 in 43 cases, with a peak at the age of 13, girls were generally slightly younger at the onset of symptoms than boys The duration of symptoms before operation ranged between 6 months and 30 years, with a mean of 4 years 4 months, and the interval between operation and review ranged between 1 year and 5 years 9 months, with a mean of 3 years 11 months

From the patient's history, the stability of the patella was placed in one of three categories, normal, recurrent subluxation, or recurrent complete dislocation The extensor mechanism was considered to be subluxing if the patient gave the typical account of the knee "giving way" without warning during walking or running, sometimes followed by an effusion into the joint (Hughston 1968)

Tenderness of the soft tissues medial to the patella was a common finding and helped to distinguish the condition from a meniscus injury, in which the tenderness is along the joint line Patients were said to have recurrent dislocation if their patella had dislocated completely more than once

Patients were considered to have chondromalacia patellae if, in addition to the symptoms of dislocation or subluxation of the patella they complained of pain or discomfort when climbing or descending stairs, getting out of a chair or rising from a squatting position, or of aching when the knee was straightened after being flexed for a long time as in a car or the theatre The pain could usually be reproduced by pressing the patella against the femur, the undersurface of the patella being tender These symptoms were classed as mild severe or absent

A medial plication of the capsule was done to avoid growth changes if the apophysis of the tibial tubercle had not fused to the tibia (6 cases) A Goldthwaite operation (Goldthwaite 1904) was done in three patients who were keen athletes because it was less likely to impair their performance than an extensive procedure requiring arthrotomy The tibial tubercle was transposed in 39 cases Hauser's oper-

Wiles, P., Andrews, P. S. & Devas, M. B. (1956) Chondromalacia of the patella. *J. Bone Jt Surg.* 38-B, 95–113

*Key words:* chondromalacia patellae; osteoarthritis; patella; knee joint, femoro patellar joint.

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location of the extensor apparatus to the medial side of the femur, but had not suffered such a dislocation during the two years prior to review. Many patients experienced difficulty with kneeling. Of the 37 knees in which a screw had been used to secure the tibial tubercle, 33 were so tender over the head of the screw that kneeling was not possible. Eight of the 15 in which a realignment had been done without the use of a screw gave rise to some complaint, but none of the six medial plications, in which the tubercle was left undisturbed, produced pain on kneeling. In three patients the symptoms of chondromalacia were worse after operation than before.

*Table 2. Stability of the extensor mechanism related to the symptoms of chondromalacia*

| | Symptoms of chondromalacia | | | |
|---|---|---|---|---|
| | None | Slight | Severe | Total |
| *Before operation* | | | | |
| Dislocation | 8 | 7 | 13 | 28 |
| Subluxation | 2 | 4 | 24 | 30 |
| Total | 10 | 11 | 37 | 58 |
| *After operation* | | | | |
| Dislocation | 1 | 1 | – | 2 |
| Subluxation | 4 | 4 | 6 | 14 |
| Normal stability | 24 | 10 | 8 | 42 |
| Total | 29 | 15 | 14 | 58 |

Two patients who underwent plication for dislocation continued to suffer dislocation but were helped by tubercle transposition when growth was complete, and six patients reported that their knees were unchanged. We could not find any clinical feature consistently associated with failure, and there was no correlation between the result and the length of history or the length of follow up.

## DISCUSSION

It is well known that recurrent dislocation of the patella is associated [illegible] ave confirmed [illegible] the patella, a [illegible] often goes unrecognised (Hughston 1968) is al-

ation (Hauser 1938) was done if the patella tendon was long or lax and its insertion needed to be moved distally as well as medially to obtain a satisfactory alignment (15 cases) If the tubercle needed only to be moved medially (24 cases) it was elevated on a distally based osteoperiosteal flap and swung to a prepared bed on the tibia where it was held with a screw (Elmslie's operation) Immobilisation after this operation is short because the continuity of the extensor mechanism is not completely disrupted If the undersurface of the patella was found at operation to be excessively fibrillated, ulcerated or eburnated, realignment was combined with patellectomy (14 cases)

## FINDINGS

A total of 42 of the 58 knees were made completely stable by operation, but 6 of the 28 which dislocated before operation subluxated afterwards (Table 1) There was no difference betwen the results of the various procedures Altogether 28 of the 30 knees (93 per cent) with subluxating patellae before operation and 20 of the 28 (62 per cent) with complete dislocation gave rise to the symptoms of chondromalacia patellae (Table 2) but these symptoms regressed after realignment, particularly if the extensor mechanism had been successfully stabilised Of the 44 cases that were realigned without patellectomy, 35 (80 per cent) had chondromalacia The symptoms of chondromalacia were improved in 26 (74 per cent), unchanged in 6 (17 per cent) and worse in 3 (9 per cent) and this improvement was obtained without shaving or drilling the articular surfaces Stability of the patella was achieved in 28 of these 35 patients, the symptoms of chondromalacia were improved in 24 of these (86 per cent), unchanged in [illegible] and worse in 1 Stability was not achieved in the remaining 7 patients, the symptoms of chondromalacia were improved in 2 (28 per cent) of these, unchanged in 3, and worse in 2

*Table 1 Stability after operation related to stability before*

| Stability before operation | | Stability after operation: Normal | Subluxation | Dislocation |
|---|---|---|---|---|
| Dislocation | (28 knees) | 20 | 6 | 2 |
| Subluxation | (30 knees) | 22 | 8 | – |
| Total | (58 knees) | 42 | 14 | 2 |

One patient had a femoral vein thrombosis with oedema of the lower limb after patellectomy and another had two early episodes of dis-

of the articular surface The symptoms of chondromalacia were more likely to regress if stability of the extensor mechanism was achieved


## ACKNOWLEDGEMENTS

We are indebted to Mr G H Fisk for permission to include his patients in this study


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*Key words* surgery operative orthopaedics knee injuries patella dislocation tendon transfers osteoarthritis chondromalacia



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most always associated with the symptoms of chondromalacia (93 per cent of cases), and that this association is stronger than that with recurring dislocation (62 per cent of cases) The explanation of this may be that the episodes of subluxation occur more frequently than the more dramatic, but less frequent, episodes of complete dislocation and that the abnormal lateral shear stress imposed on the articular cartilage of the patella is consequently greater in patients with subluxation

The symptoms of chondromalacia improved in 74 per cent of all patients after realignment of the extensor mechanism, and this figure is similar to the results of patellaplasty (Cave & Rowe 1950), shaving or drilling the articular cartilage (Wiles et al 1956, Wiles et al 1960), and tibial tubercle transposition (Devas & Golski 1973) Our own series differs from others in relating improvement in the symptoms of chondromalacia to the attainment of patella stability, if the patella mechanism was made stable, the symptoms of chondromalacia were more likely to improve (86 per cent of cases) than if stability was not achieved (28 per cent of cases) Patients who have the symptoms of chondromalacia as well as those of patella instability can, therefore expect to derive considerable benefit from realignment of the extensor mechanism of the knee

## CONCLUSIONS

Instability of the extensor mechanism is important in the aetiology of chondromalacia patellae and the symptoms of chondromalacia are likely to regress in most patients with dislocation or subluxation of the patella when the patella mechanism has been made stable This improvement occurs without shaving or drilling of the patella and is probably due to the reduction of abnormal shear stresses on the articular cartilage The use of a screw to secure the tibial tubercle is often associated with persistent pain, tenderness and disability

## SUMMARY

Fifty eight realignment operations for dislocation or subluxation of the extensor mechanism are described Patellectomy was combined with realignment in 14 Thirty-five of the 44 patients (80 per cent) in whom the patella was retained also had chondromalacia patellae which improved after realignment in 26 (74 per cent) without shaving or drilling

*Figure 1*

*Figure 2*

*Figures 1 and 2 Lateral roentgenograms of both knees on the day of injury showing high riding patellae*

with interrupted silk sutures through drill holes made in the patella. The retinacula were repaired with interrupted stitches of No 3 chromic catgut A long leg cast was applied postoperatively

Seven days later a similar technique was used to repair the right knee which revealed a similar picture

Six weeks after surgery the casts were removed and active movement was initiated He regained strength and complete range of movement about 15 weeks after the first operation

The histological examination showed an infiltration by mononuclear cells with diffuse calcification and some necrotic foci

## DISCUSSION

Many cases of spontaneous tendon rupture, particularly in the hand and wrist have been reported in patients with rheumatoid arthritis (Kersley 1948 Laine & Vainio 1955, Ehrlich et al 1959), but infra patellar tendon rupture is less common in this disease We have been able to find only one such case reported in the literature (Razzano et al 1973)

Acta orthop. scand. 46, 700-703, 1975

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# SIMULTANEOUS AND SPONTANEOUS BILATERAL RUPTURE OF THE PATELLAR TENDON IN RHEUMATOID ARTHRITIS

*A Case Report*

ANGEL PEIRÓ, RAMON FERRANDIS, LUIS GARCIA & ENRIQUE ALCAZAR

*Accepted 2 I 75*

Tendon rupture in patients with rheumatoid arthritis is not rare, but simultaneous and spontaneous bilateral rupture of the patellar tendon is very unusual.

We present a case of this type of tendon rupture.

## CASE REPORT

A 27-year-old farmer was admitted to hospital complaining of pain and swelling in both knees

Five years previously he was diagnosed as having rheumatoid arthritis because he had erratic pain in the small joints and a positive serology for that disease He was treated with aspirin which improved the clinical picture, but he did not receive cortisone At no time did he complain of pain, swelling or weakness in the knees

One hour prior to his admission to hospital, he was going downstairs, and had an acute onset of pain and weakness in his left knee He tried to support his weight on his right leg and the right knee also became painful and weak He grabbed the handrail and prevented himself from falling Afterwards he was unable to stand up or straighten either of his knees

On physical examination he had a swelling in both knees with a clear gap in both patellar tendons just below the patellae, which were displaced proximally Passive flexoextension was possible with some limitation due to pain

X-rays showed bilateral high-riding patellae No fracture at the patellae or anterior tuberosity of the tibia were seen The effusion was evacuated and a compressive dressing was applied to each knee

Two days after his admission the left knee was operated on A complete rupture of the patellar tendon, just below the patella, was found extending into the retinacula about 3 cm on each side, medially and laterally The rupture was repaired

Strejček, J & Popelka, S (1969) Bilateral rupture of the patellar ligaments in systemic lupus erythematosus *Lancet* ii, 743

Wener, J A & Schein, A J (1974) Simultaneous bilateral rupture of the patellar tendon and quadriceps expansions in systemic lupus erythematosus A case report *J Bone Jt Surg* 56 A, 823

*Key words* rupture, spontaneous, tendon injury, arthritis, rheumatoid, knee joint

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Simultaneous complete bilateral rupture of the quadriceps tendon has been reported frequently, but bilateral rupture of the infrapatellar tendon is not so common (Martin et al 1958, Strejček & Popelka 1969 Razzano et al 1973, Rascher et al 1974, Wener & Schein 1974) The last-mentioned reference was the one in which a case of simultaneous bilateral and spontaneous rupture of the patellar tendon was reported

Tendon rupture occurs most commonly in men past middle age (James 1938) The age of this patient makes this case quite unusual

Cortisone has been implicated as one of the predisposing factors in tendon rupture (Strejček & Popelka 1969, Razzano et al 1973), but this patient never received this drug

The histopathological findings are those of avascular changes and fibrinoid degeneration, the latter being a typical finding in collagen diseases (Small 1961)

## SUMMARY

A case of rupture of the patellar tendon in a patient with rheumatoid arthritis is presented The age of this patient (27 years) makes this case quite uncommon The rupture was bilateral, simultaneous and spontaneous The absence of previous cortisone administration rules out this drug as a cause of the tendon rupture

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*Key words* rupture spontaneous, tendon injury, arthritis rheumatoid, knee joint

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Acta orthop scand 46, 704–706, 1975

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# RESTRAINT IN THE TREATMENT OF A BOWED TIBIA ASSOCIATED WITH NEUROFIBROMATOSIS

G K Rose

Accepted 3 ii 75

A boy, then aged 9 months, was seen in November, 1952 with bowing of the right tibia, as shown in Figure 1 Apart from more than 20 "cafe au-lait" spots typical of neurofibromatosis no other abnormality was found on skeletal survey or full paediatric investigation Apart from unavailing attempts during the first year to modify the deformity by serial plasters he has had no further treatment He has had no complaints and no loss of function Since leaving school at the age of 15, 7 years ago, he has been employed doing heavy work in a brewery stacking 500 cases a day each weighing 30 lbs He has never had problems in obtaining or wearing shoes and can run without difficulty, his gait is normal, his legs of equal length and he has no callosity under the sole of either foot

Clinically he still retains considerable bowing and radiologically (Figure 2) the apex of the curve has moved proximally with growth and the angular deformity has decreased from 42° to 22° His right ankle joint is tilted 17°, in relationship to the standing surface, compared with the left It shows no sign of degenerative change

## DISCUSSION

*No operative treatment was considered in this case* because of the known dangers of pseudarthrosis, a fear confirmed by Hardinge (1972) who in 100 cases of pseudarthrosis found that 21 followed corrective osteotomy Although this complication can be treated by the specialised procedures of MacFarland (1939), Boyd (1941) and Charnley (1956) the treatment is necessarily prolonged and often results in shortening of the affected leg up to 3½ inches (7 7 cm)

In any case if operative treatment is considered essential it should be delayed at *least until after 33 months and ideally until late adolescence*

*Figure 1*

*Figure 2*

when correction of the alignment of the ankle with the standing surface can then be undertaken through *normal* bone

SUMMARY

A 20 year follow up in no way suggests that an active programme of treatment could have improved this patient's function and clearly it could have resulted in much worse cosmesis

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*Key words* bowed tibia, neurofibromatosis, tibia, treatment


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Acta orthop scand 46 707–708, 1975

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# FRACTURE OF THE HUMERUS FROM ARM WRESTLING

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Accepted 28 ii 75

Fractures of the humeral shaft as a result of violent muscle activity (e g throwing) are well known These are spiral fractures and usually localized between the middle and the distal one third of the humerus

The mechanical reasons are complex and have been discussed by several writers (Herzmark & Klune 1952, Arfwidsson 1957, Chao et al 1971, Gregersen 1971)

Within a short period of time the authors have treated two patients with this type of fracture of the humerus, in both cases associated with arm wrestling In this game the two opponents sit face to face with their elbows placed firmly on a surface, gripping their right hands and trying to force each other's arm down There is no record of an earlier report of this type of fracture

## CASE REPORTS

*Case 1*

A 23 year old man (a weight lifter) presented with a spiral fracture through the distal part of the right humerus On admission a partial n radialis paresis distal to the fracture was found

The injury had happened in association with arm wrestling During a treatment period of 24 hours with a hanging cast a total n radialis paresis developed and the patient was therefore operated on. The radial nerve was found to be lying over the sharp distal fragment of the fracture but was not macroscopically severed. The fracture was fixed with an AO compression plate and the postoperative course was uneventful After 2 months the fracture had healed and complete radial nerve function was restored

*Case 2*

A 74 year old man presented with a spiral fracture of the distal part of the right humerus which had been caused by arm wrestling There was no sign of nerve or blood vessel damage and the patient was therefore treated with a hanging cast for 2 months Three months after the accident the fracture had healed and movement in the extremity was satisfactory

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*Key words* bowed tibia, neurofibromatosis, tibia treatment

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# BONE MINERAL IN PATIENTS WITH OSTEOARTHROSIS OF THE HIP

E M ALHAVA, K KETTUNEN & P KARJALAINEN

Accepted 25 III 75

Foss & Byers (1972) showed that patients suffering from primary osteoarthrosis have a larger bone mass at the second metacarpal in comparison both with patients suffering from femoral neck fracture and also with the general population Roh et al (1973) postulated that the larger metacarpal bone mass of patients with osteoarthrosis of the hip was due to normal endosteal resorption and to increased periosteal apposition as compared with controls matched for age and sex Using photon absorption, they also demonstrated that the mineral content of the forearms of osteoarthrotics was higher than that of controls (Roh et al 1974) These observations justify the proposition that the aetiology of primary osteoarthrosis could be a general disturbance in bone mineral metabolism, for instance overproduction of growth hormone

The purpose of the present investigation was to measure the bone mineral linear density (g/cm) and density (g/cm³) of the forearm bones by the Am 241 gamma ray attenuation method, and to measure the cortical index and combined cortical thickness of the second metacarpals, all in patients with osteoarthrosis of the hip, and also to compare the results with measurements from a series of subjects with healthy bones

## MATERIAL AND METHODS

Eleven women and 10 men with primary osteoarthrosis of the hip grades 3–4 according to Kellgren s classification (1963), were studied The patients were otherwise healthy and they had no known diseases affecting the bone [illegible] material [illegible]
The m[illegible]
female [illegible] for males 33–71

The bone mineral linear density (g/cm) and density (g/cm³) were determined

## DISCUSSION

It is apparent that arm wrestling can be connected with a typical lesion mechanism. A powerful muscle activity is created in the shoulder joint by the strong internally rotating pectoralis major, subscapularis, teres major and latissimus dorsi muscles, while the elbow joint is fixed by the biceps, brachialis, brachio-radialis and extensor carpi radialis longus muscles. At the same time as the forearm is pressed down a violent torque is exerted upon the diaphysis of the distal part of the humerus. The torque is transmitted by the forearm acting as a lever because the elbow joint is fixed in its flexed position. In the first case reported the unusually well-developed arm muscles of the patient might have contributed to the ensuing fracture.

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*Key words:* humeral fractures, athletic injuries, biomechanics, exertion, torsion, sport medicine.

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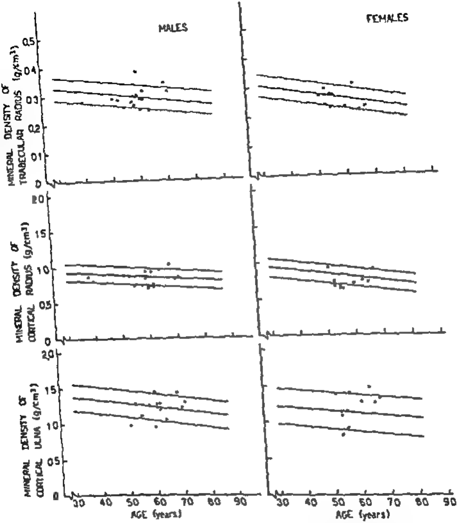


*Figure 1 b*

*Figure 1 Bone mineral a) linear density λ (g/cm) and b) density ρ (g/cm³) The regression line with its 1 SD is plotted for the controls from the age of 30*

## RESULTS

The bone mineral linear density (g/cm) of the patients did not differ in a statistically significant manner at any measuring point from that of the controls The mineral density (g/cm³) of the cortical radius of the female patients was statistically significantly lower than that of the

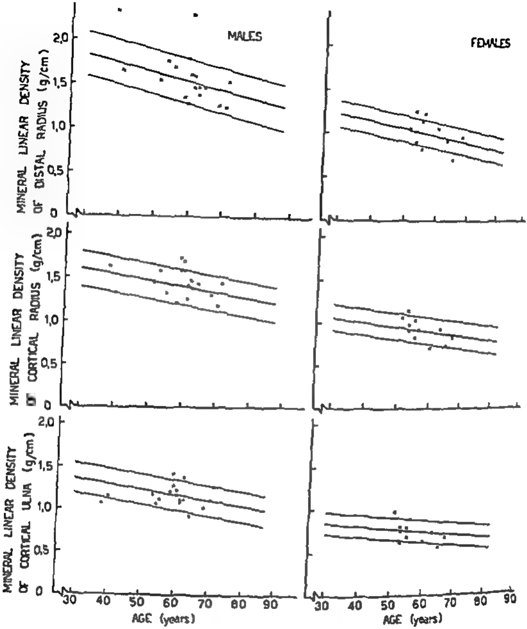


*Figure 1 a*

from the left antebrachium, from the cortical and cancellous bone area, by the Am-241 gamma ray attenuation method (Cameron & Sorenson 1963, Karjalainen 1973) The cortical indexes and combined cortical thicknesses of the second metacarpals were measured with a caliper from postero-anterior radiographs (Barnett & Nordin 1960)

In the statistical analysis of the results a comparison was made with a control material The control values were taken at a point corresponding to the patient's age from the regression line for the left hand, calculated within the range of age distribution of the patients (Figure 1 a, b)

## DISCUSSION

The osteoarthrotics of our series had either been operated on shortly before for their hips or the decision to perform the operation had been made before they were selected for our study. The operated patients were mobilized immediately after the surgery and had no serious complications. The criteria for exclusion of known diseases affecting the bone mineral content were (Vaughan 1970): persons who had taken hormones and who had or had had an endocrinological disease, rheumatoid arthritis, malignant tumours, sarcoidosis, chronic nephropathy or renal calculi, malabsorption, osteomalacia, hemiparesis or other paresis, asthma or epilepsy; persons who had undergone intestinal surgery apart from appendectomy were also excluded. In addition long term users of psychopharmaceutical drugs and diuretics were also ruled out. The criteria were same for the osteoarthrotics and controls and the selection was made by the same person. The observers who made the measurements were the same for both series. The mean age, heights and weights of the osteoarthrotics did not differ statistically from those of the controls of the same age range.

The gamma ray attenuation method for measuring *osteoporosis* has proved to be the most accurate and reliable one (Shimmins et al. 1972) and is suitable for screening studies (Alhava 1974). Foss & Byers (1972) in measuring the mineral mass of the second metacarpals stated that osteoarthrosis is associated with above average bone density, and that osteoporosis and osteoarthrosis do not normally occur together. They also found that patients with hip fractures had a lower mineral density than controls. They presented only one case of osteoarthrosis in a series of 140 hip fractures. Alhava (1974) in his consecutive series of 104 hip fracture patients found five cases with concomitant arthrosis of the hip. Using the Am 241 gamma ray attenuation method Alhava & Karjalainen (1973b) also found that the mineral density of the distal radius was statistically significantly lower in patients with fractured hips than in control series. Roh et al. (1973) confirmed the observation of Foss & Byers that osteoarthrosis of the hip is associated with above average cortical bone mass at the second metacarpal bone. They proposed that this may be due to some kind of over activity of growth hormone.

We found that the bone mineral linear density (g/cm) and density (g/cm³) of the forearm bones were almost the same in osteoarthrotics and controls with the exception of the female cortical radius where the

controls ($P < 0.02$). There were no statistically significant differences at the other measuring points (Table 2).

*Table 1. Age, height, and weight of patients and controls. The controls were selected from the healthy persons with corresponding age range to the patients. The t test was used in the comparison*

| | Sex | Patients | | Controls | | Significance | | |
|---|---|---|---|---|---|---|---|---|
| | | n | Mean±1SD | n | Mean±1SD | t | $P <$ | |
| Age (years) | F | 11 | 57±5 | 17 | 58±5 | 0.70 | 0.50 | NS |
| Height (cm) | F | 11 | 157±7 | 17 | 158±7 | 0.35 | 0.80 | NS |
| Weight (kg) | F | 11 | 65±8 | 17 | 69±11 | 1.09 | 0.30 | NS |
| Age (years) | M | 18 | 58±9 | 34 | 55±10 | 1.39 | 0.20 | NS |
| Height (cm) | M | 18 | 172±6 | 34 | 170±6 | 1.04 | 0.40 | NS |
| Weight (kg) | M | 18 | 77±13 | 34 | 74±13 | 0.93 | 0.40 | NS |

NS = not significant

*Table 2. Bone mineral linear density λ (g/cm) and density ρ (g/cm³) in osteoarthrotics and controls (1 = distal cancellous radius, 2 = cortical radius and 3 = cortical ulna). t test, paired comparison*

| | | n | Mean±1SD (patient) | Mean±1SD (control) | Significance t | $P <$ | |
|---|---|---|---|---|---|---|---|
| F | $\lambda_1$ | 11 | 1.01 ± 0.17 | 1.00 ± 0.04 | 0.31 | 0.80 | NS |
| F | $\lambda_2$ | 11 | 0.92 ± 0.14 | 0.91 ± 0.03 | 0.35 | 0.80 | NS |
| F | $\lambda_3$ | 11 | 0.74 ± 0.13 | 0.76 ± 0.02 | −0.54 | 0.70 | NS |
| M | $\lambda_1$ | 18 | 1.60 ± 0.30 | 1.52 ± 0.08 | 1.18 | 0.30 | NS |
| M | $\lambda_2$ | 18 | 1.44 ± 0.16 | 1.38 ± 0.06 | 1.32 | 0.30 | NS |
| M | $\lambda_3$ | 18 | 1.15 ± 0.12 | 1.21 ± 0.04 | −2.00 | 0.10 | NS |
| F | $\rho_1$ | 11 | 0.258 ± 0.030 | 0.265 ± 0.009 | 0.88 | 0.30 | NS |
| F | $\rho_2$ | 11 | 0.73 ± 0.09 | 0.83 ± 0.03 | −3.11 | 0.02 | |
| F | $\rho_3$ | 11 | 1.20 ± 0.21 | 1.13 ± 0.02 | 1.06 | 0.40 | NS |
| M | $\rho_1$ | 18 | 0.286 ± 0.032 | 0.283 ± 0.014 | 0.38 | 0.80 | NS |
| M | $\rho_2$ | 18 | 0.83 ± 0.09 | 0.88 ± 0.02 | −1.88 | 0.10 | NS |
| M | $\rho_3$ | 18 | 1.19 ± 0.14 | 1.24 ± 0.04 | −1.31 | 0.30 | NS |

NS = not significant

There were no differences between the patients and controls as regards the cortical index and the combined cortical thicknesses of the second metacarpals.

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Key words osteoarthrosis, osteoporosis, Am 241, hip fracture


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density was lower than in controls, perhaps by chance Moreover, the cortical indexes and combined cortical thicknesses of the second metacarpals of these two groups did not differ in either sex

Our results *contradict the findings of Foss & Byers (1972)* and Roh et al (1973, 1974) One explanation for this may be the different compositions of the control series in the various studies Our control series had healthier bones than the general population, because all known bone-affecting diseases *and* drugs were used as criteria for exclusion We assume that the controls of Foss & Byers represented the general population, but those of Roh et al, including ambulant *psychiatric patients and patients with tuberculosis, were osteoporotic* (Engh et al 1968, Nilsson 1970) Moreover, racial and geographical factors may influence the bone mineral content (Chalmers & Ho 1970, Alhava & Puittinen 1973)

Several investigations show that changes in the peripheral bones are similar to those in axial bones (Smith & Frame 1965, Nordin et al 1970, Siegelman 1970) A longitudinal study is needed to determine the *correlations between bone mineral densities and osteoarthrosis*, and the possible effects of physical activity, over-activity of growth hormone etc on these two factors

## SUMMARY

A series of 29 patients with primary osteoarthrosis of the hip were studied to evaluate their bone mineral status A comparison was made *with a series of persons with healthy bones The bone mineral* content of the osteoarthrotics, as measured either by gamma ray attenuation in the forearm bones, or as cortical indexes, or obtained from the combined cortical thicknesses of the second metacarpals from the radiographs, was not higher than in the control series These findings do not support the concept that patients with osteoarthrosis tend to have a higher "mineral density" than healthy people

## ACKNOWLEDGEMENT

This work was supported by the National Research Council for the Medical Sciences

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Acta orthop scand 46, 716–726, 1975

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# EARLY CHANGES IN THE COMPOSITION OF RABBIT ARTICULAR CARTILAGE FOLLOWING EXPERIMENTALLY PRODUCED INTRA-ARTICULAR FRACTURES

## *A Histological and Thermoanalytical Study*

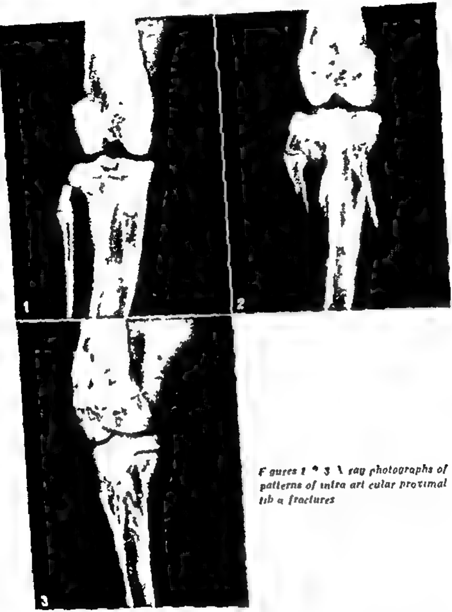
T A Farkas, T Biro & M Bihari-Varga

Accepted 28 iii 75

The treatment of intra-articular fractures remains an unsolved problem, until the reasons for the development of posttraumatic arthritis are cleared up satisfactorily Based on numerous clinical observations of intra-articular fractures, factors such as surface incongruity, joint instability, deformation of the axis of weight transmission, prolonged immobilisation, and advanced age of the patient are already well appreciated, but other apparent factors accounting for the high incidence of post-traumatic arthritis are not yet fully understood Some authors, on the basis of the effects of haemarthrosis, lipoarthrosis, enzymatic breakdown and malnutrition in basic experiments, emphasize the importance of initial joint trauma (Schultz et al 1973) The object of the work described in the present paper was to study the possible early damages taking place in the structure and composition of articular cartilage as a result of joint trauma To this end intra-articular fractures were produced experimentally and the cartilage changes investigated by histological, histochemical and thermoanalytical methods

## MATERIALS AND METHODS

Thirty five 8 month old rabbits were used in the experiments The use of not fully mature animals avoided possible degenerative changes related to aging and the relative thickness of the articular cartilage provided more material for processing The animals were housed under normal conditions and kept on stock diet Under




*Figures 1 – 3 X ray photographs of patterns of intra articular proximal tibia fractures*

intravenous barbital anaesthesia intra articular fractures were produced in the right tibial condyles of each animal By means of a modified gripping tool bilateral compression was exerted on the condyles Squeezing the spongy bone of the condyles the padded arches of the tool were closed to a standard width of approximately 6 mm The resulting intra articular fractures were verified in all instances on X ray

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out on the basis of the TG curve, but with the help of the DTG curve, which shows transformations accompanied by weight change and their characteristic temperatures DTA curves served for the qualitative evaluation of processes which were connected with weight and heat effects of a parallel nature but of opposite sign In the derivatograph the evolution of the structurally bound water content, the decomposition of glycosaminoglycans (Bihari Varga 1971 a) and of proteins (Bihari Varga 1971 b) took place at well defined characteristic temperatures and thus could be studied individually Inorganic compounds turned up in the form of a thermostable residue

## RESULTS

### *Morphological findings*

Gross examination of the injured joints on the 3rd day after fracture revealed massive haemarthrosis which presented after 1 week as small blood clots and which from the 2nd week after injury was absent Fragmentation and displacement of the tibial articular surface was noted in seven cases out of the 35 From the 2nd week granulation tissue could be seen, but even in the group sacrificed 8 weeks after fracture original cartilage cover was clearly separable On the femoral condyles the cartilage surfaces showed basically no variations

On microscopic examination of sections from the 3rd day (Figure 5)

*Figure Articular cartilage from the knee joint of a rabbit 3 days after injury Slight loss of matrix staining (Periodic acid-Shiff and Alcian blue × 12)*

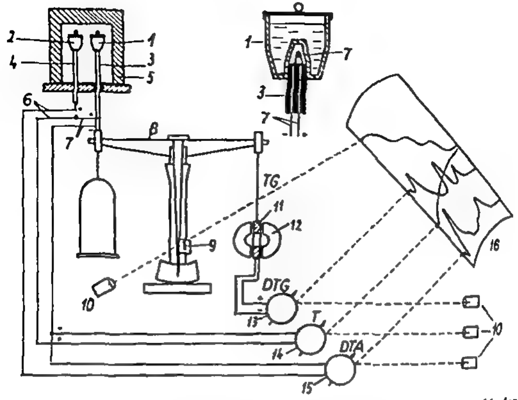


*Figure 4 Structure of the derivatograph 1—crucible for the sample, 2—crucible for the inert substance, 3, 4—porcelain tube, 5—electric furnace, 6, 7—thermocouples 8—balance, 9—optical slit, 10—lamps, 11—coil, 12—permanent magnets, 13, 14, 15—galvanometers, 16—photographic paper*

photographs taken of the injured knee joint (Figures 1, 2, 3) The injured limbs were left free to move The opposite knee joints served as controls

At appropriate time intervals (3 days, 1, 2, 3, 4, 7 and 8 weeks after the induction of fracture) 5 animals were sacrificed respectively Immediately after death, the proximal part of the tibia was isolated and a 2 mm thick osteochondral layer was removed from the largest extension of the injured condyles for histology Decalcified paraffin sections were prepared and stained with HE and PAS Alcian blue The articular cartilages of the femoral and tibial condyles were excised and subjected to thermal analysis

In order to follow the healing process of the fractures, callus samples from each stage of every experiment were collected from the fractured proximal tibia and processed by the thermoanalytical method

Thermal analysis was carried out using a Paulik Paulik Erdey (Paulik et al 1958, Paulik & Paulik 1971) MOM Derivatograph (Figure 4) The instrument measured and recorded simultaneously the weight change (TG curve), rate of weight change (DTG curve) and enthalpy change (DTA curve) as functions of temperature in the same sample

The material, approximately 50 mg was weighed into a platinum crucible The heating rate was 2°/min up to 900° C The quantitative determination was carried

*Figure 8 Articular cartilage from the knee joint of a rabbit 4 weeks after injury Stepwise depression of the cartilage surface Chondrocyte clusters (Haematoxylin and eosin × 40)*

and 1st week (Figure 6) a slight decrease in matrix staining appears to occur in the PAS Alcian blue stained sections but no essential difference from the normal is noted Starting from the 2nd week signs of regeneration mitotic figures with chondrocyte clusters appear in the original cartilage cover The slide from the group sacrificed 4 weeks after the fracture shows a site of injury on the articular surface (Figure 7) Under the original impressed cartilage cover a subchondral horizontal cleft is visible The site of bony fracture is filled up with cartilaginous callus The mechanically deranged and compressed original cartilage layer is covered by a sheet of pannus Adjacent to the injured part chondrocyte clusters appear in the original cartilage A similar appearance of the original cartilage is seen on a section from the same group with stepwise depression of the original cartilage surface (Figure 8) A cartilage sample from the group sacrificed 7

*Figure 6 Articular cartilage from the knee joint of a rabbit 1 week after injury Deficient metachromasia (Periodic acid-Schiff and Alcian blue, × 20)*

*Figure 7 Articular cartilage from the knee joint of a rabbit 4 weeks after injury Site of osteochondral fracture Depressed articular surface covered by pannus Fibrocartilaginous regeneration Chondrocyte clusters (Haematoxylin and eosin, × 20)*

*Figure 8 Articular cartilage from the knee joint of a rabbit, 4 weeks after injury Stepwise depression of the cartilage surface Chondrocyte clusters (Haematoxylin and eosin, × 40)*

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*Figure 10 Articular cartilage from the knee joint of a rabbit 8 weeks after injury The articular cartilage is overgrown by fibrous tissue The original cartilage structure is well recognisable (Haematoxylin and eosin × 20)*

### *Demonstration of fracture healing by thermal analysis*

Thermoanalytical studies on callus (Figure 12) indicated an increase of glycosaminoglycan content compared to the unfractured bone in good agreement with data from the literature Glycosaminoglycan concentration decreased gradually during calcification Structurally bound water content showed a maximum as a function of time, reaching its peak value at about 3 weeks after injury The composition of the regenerating bone resembled that of the unfractured bone in the 8th post traumatic week, and thus the healing process could be regarded as completed

## DISCUSSION

As described previously (Bihari Varga et al 1975, Farkas et al 1974) in accordance with the results of numerous investigators, early cartilage lesions were found to be strikingly similar, irrespective of the

*Figure 9 Articular cartilage from the knee joint of a rabbit, 7 weeks after injury Almost normal cartilage structure and metachromasia (Periodic acid-Schiff and Alcian blue, × 50)*

weeks after injury, with normal acid mucopolysaccharide pattern on the PAS Alcian blue stained section shows an almost normal appearance (Figure 9) On a section 8 weeks after injury, the original articular cartilage in a depressed and buried position is still well recognizable, with normal tide mark and with chondrocyte clusters (Figure 10)

*Results of thermal analysis*

Thermal analysis showed slight, not significant alterations in the chemical composition and structure of the cartilage tissue of the injured joint within the first 8 weeks of the healing period (Figure 11)

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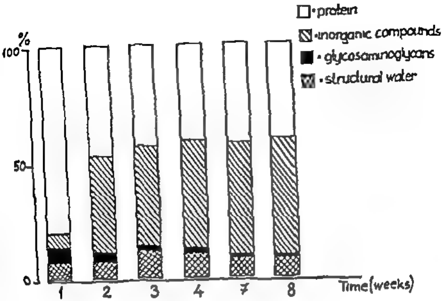


*Figure 12 Changes in the composition of callus*

changes in the articular cartilage outside the defect area over periods up to 20 weeks At 10 and 52 weeks however, some loss of meta chromatic material and superficial fibrillation occurred with a tendency towards lower values of total hexosamines

Clinical observations indicate a similar slow development of post traumatic arthritis with rising incidence even more than 2 years after trauma

From our experiments it can be concluded that there is no gradual deterioration in the structure and composition of articular cartilage after intra articular fracture at observation times up to 8 weeks which would lead directly to irreversible changes consistent with arthritis Within this period the early effects of trauma subsided

## SUMMARY

Intra articular fractures were produced in rabbit knee joints The articular cartilage of the injured joints was processed histologically and analysed by a complex thermoanalytical method It was demonstrated that intra articular fractures in the early stages have essentially no irreversible damaging effects on the composition of articular cartilage of injured joints

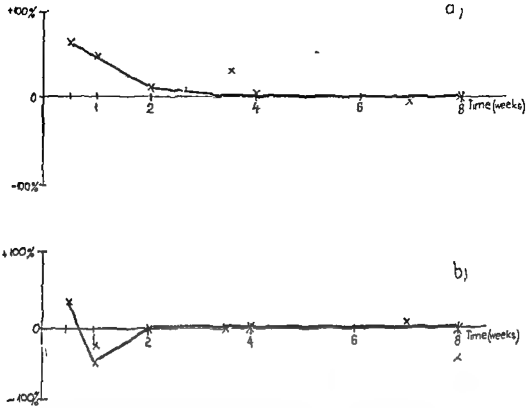


*Figure 11. Percentage changes in structural water content (a) and glycosaminoglycan content (b) of rabbit articular cartilage as a function of time after experimental induction of fracture. Data are referred to those measured in the corresponding cartilages of the control extremity.*

method used for the production of degenerative alterations, viz. a gradual deterioration in the course of the first week, resulting in a significant decrease in the proteoglycan content of the matrix without change in the collagen, followed by a complete repair of the composition of the cartilage towards the 6th week.

In the present experiments a similar pattern of aspecific early reaction of the cartilage of injured joints is suggested by the histological sections. The morphological appearance, however, never recovers to normal during the early phase. The alterations are focal in nature, as revealed by histology, and so slight that no significant alterations in the average composition of the cartilage could be measured by thermal analysis.

For a possible relationship with late arthrosis, the experimental results of Hjertquist & Lemperg (1971) should be examined. After having produced osteochondral defects in the articular surface of rabbit femoral heads, these authors could observe no degenerative

Acta orthop scand 46, 727–736, 1975

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# INFANTILE CORTICAL HYPEROSTOSIS

## *Follow-up of 29 Cases*

A Finsterbush & M Rang

Accepted 21 III 75

An infant suffering from a disease characterized by hyperirritability, thickening of the bones and painful swelling of the overlying soft tissues, was described by George Roske (1930) A similar clinical picture was described in 1945 by Caffey & Silverman (1945), who differentiated a new syndrome which they designated Infantile Cortical Hyperostosis Since then the entity has been more readily recognized and seemingly more frequent Recognition of this benign disease is of importance in differential diagnosis of infectious, tumorous, neurologic and traumatic conditions of bone in infancy We have reviewed the clinical picture, radiological distribution of the bone lesions and the follow-up of the condition in 29 patients, seen in the Hospital for Sick Children, Toronto, in the last 20 years

## MATERIAL AND METHODS

Twenty nine cases with infantile cortical hyperostosis (Caffey's disease) were admitted to the Hospital for Sick Children in the years 1953–1972 The charts and x rays of these patients were revised and special interest was concentrated on the later notes on admission and/or clinical notes in order to follow the possible late complications of the disease Twelve children were readmitted to the hospital, or examined in the outpatient clinic, for intercurrent illness or trauma It is of interest to note that three of the children were treated for spastic bronchitis and one for *another allergic phenomenon* No complication or any late signs of the disease above the age of 2 years were found in this material

Pregnancies of the mothers were normal and full term One delivery was Pitocin induced two babies were delivered with low forceps and one following Cesarian section There were 15 females and 14 males Average age [illegible] sentation at [illegible] itted at the

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*Key words* injury, cartilage histology, derivatography, composition


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Pregnancies of the mothers were normal and full term One delivery was Pitocin induced two babies were delivered with low forceps and one following Cesarian section There were 15 females and 14 males Average age at time of presentation at the hospital was two and a half months The youngest patient was admitted at the age of two weeks the oldest was four and a half months old (*Table 1*)

*Figure 1. 3-month-old baby who on admission presented jaw swellings, more so on one side. At this stage roentgenological examination was negative.*

*Figure 2 Same baby as Figure 1, 4 months old One month after mandibular involvement Unilateral painful leg swelling has appeared*

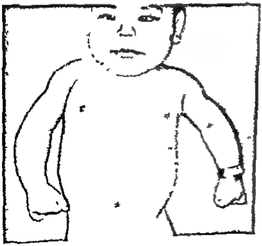

*Figure 3 2 month old baby with bilateral jaw and unilateral forearm swellings*

*Figure 4 a 3 month old baby who on admission presented swelling around the left clavicle and also slight torticollis*

*Figure 4 b Same baby as in Figure 4 a 2 weeks later Note the cloudy opacities around the affected clavicle*

*Figure 4c Same baby 6 weeks later Note the sharp border of the new bone*

*Table 1 Age distribution*

| Age at admission (in months) | 0 | ½ | 1 | 1½ | 2 | 2½ | 3 | 3½ | 4 | 4½ |
|---|---|---|---|---|---|---|---|---|---|---|
| Number of cases | – | 1 | 3 | 7 | 3 | 3 | 6 | 3 | 2 | 1 |

Although most infants were restless feverish very irritable and pale some with poor appetite, they were in relatively good condition and mostly well developed None was in a serious clinical condition

The hyperirritability and loss of appetite were present early in the disease and preceded the swelling of the soft tissues by a few days or weeks Soft tissue swellings appeared suddenly and were characterized by a painful tender waxy hardness (Figures 1, 2, 3) The swellings began before the roentgenographic changes appeared in the underlying bone (Figure 4) Not all bones were affected at the same time In 17 babies gradual involvement of different bones was noted (Figure 5) Only six had solitary bone involvement another six had bilateral involvement of the same bone In seven cases lesions previously noted to be healing became reactivated One of these babies had five recurrences during the first 10 months of his life

On clinical examination in addition to the local swelling tenderness and extreme general irritability, seven babies developed conjunctivitis with sterile discharge In four cases an enlarged liver was noted

The distribution of the bone involvement is given in Table 2 Six cases presented one bone involvement only four in the mandible one in the scapula and one in the clavicle Five cases had bilateral involvement of the same bone five in mandibulae and one in both humeri

*Figure 5 Left side rib hyperostosis in a 4 month old baby Unilateral mandibular involvement was noted at the age of 2 months*

*Table 2 Distribution of bone involvement*

| | Unilateral | Bilateral |
|---|---|---|
| mandible | 23 | 11 |
| zygoma | 3 | |
| skull | 1 | |
| ribs | 8 | 3 |
| clavicle | [illegible] | 1 |
| scapula | 4 | |
| humeri | 3 | 3 |
| ulnae | 5 | 2 |
| radius | 5 | [illegible] |
| femur | 2 | |
| tibia | 6 | 1 |
| fibula | 2 | |

## LABORATORY DATA

Anemia with an iron deficiency pattern was present in most cases The most prominent changes were found in hemoglobin levels (Table 3) Raised white blood count was found in 18 cases (Table 4) Erythrocyte sedimentation rate (Westergren method) was increased in most cases

partially due to the anemia. In seven cases ESR was above 100 mm/1 h. The calcium and phosphorus levels were normal. Alkaline phosphatase levels were increased above 25 KA units up to 70 KA in 14 cases.

*Table 3. Hemoglobin levels*

| Hemoglobin level in gc per cent | Number of cases |
|---|---|
| 11 and above | 3 |
| 11–9 | 14 |
| 9–6.8 | 12 |
| | 29 |

*Table 4. WBC distribution*

| WBC per $mm^3$ | Number of cases |
|---|---|
| 12,000 and lower | 11 |
| 12,000–20,000 | [illegible] |
| 20,000–38,400 | 9 |
| | 29 |

## DISCUSSION

The cause of infantile cortical hyperostosis is still disputed. Familial occurrence has been described, as reported by Pajewski & Vure (1967), Holman (1961), Sidbury & Sidbury (1954), Tampas et al. (1961), Veller & Laur (1953) and Barba & Freriks (1953), suggesting a possible hereditary factor. Allergy to milk, high familial occurrence of asthma and good response of the disease to corticosteroids suggested an allergic background to the disease, as put forward by Morrison (1957) and Bowman et al. (1961). Seven cases in the present review, who developed swollen eyelids, conjunctivitis, also suggest an allergic background for this condition. The recurrency rate in these cases was higher than in the other cases, and they responded well to steroid therapy. Four children in this group developed allergic diseases, as found in the follow-up. Negative cultures and serological tests eliminate infection as a causative factor. Possibility of vitamin C deficiency or hypervitaminosis (vitamin A) was investigated and ruled out as a causative factor.

The pathological changes of infantile cortical hyperostosis have been studied in a few cases by Dickson et al. (1957), Eversole et al. (1957),

Holman (1961) and Sherman & Hellyer (1950) Acute inflammation occurs at an early stage of the disease and this is associated with loss of the periosteum and occasionally with reduction of compactness of the subperiosteal layers of the original bone as definite histological structures Simultaneously there is a marked fibrous and osteoblastic reaction with much osteoid deposition in the loose fibrous tissue surrounding the bony trabeculae The whole process extends to invade the surrounding soft tissue including muscles Eventually the inflammation subsides spontaneously and the inflamed callus like process becomes organized into normal trabecular bone which is covered by a thickened periosteum from which scar tissue extends out into the soft tissues At this later stage a subperiosteal cap of lamellar bone without inflammation is seen

Specimens taken from the soft tissue swellings have exhibited hyperplasia of the collagen elements and foci of fibrinoid degeneration as reported by Sauterel & Rabinovitz (1961)

A modification of arteriolar intima resulting in an inadequate vascular supply to the involved bone with subsequent failure of normal perichondral bone formation and a compensatory increase of endosteal bone formation in the later stages was proposed by Sherman & Hyllyer (1950) and by Barba & Freriks (1953) as a possible pathogenesis of this condition

The differential diagnosis of infantile cortical hyperostosis includes trauma osteomyelitis parostitis hypervitaminosis A scurvy syphilis and malignant tumors such as Ewing sarcoma or metastatic involvement such as neuroblastoma The majority of these conditions can be ruled out by 1) the narrow age group limitation of between birth and 5 months 2) the typical clinical picture including irritability swelling osseous lesions and self limitation of the disease 3) mandibular involvement in most cases Serological biochemical and other laboratory tests will aid in ruling out other conditions Only in a very atypical case when the question of malignancy or infection arises must the diagnosis be confirmed by a biopsy

The age limitation of infantile cortical hyperostosis is the most striking feature of this entity This was true in the present review too although recurrence or other bony involvement was observed up to the age of 8 months The disease has been observed occasionally in newborn infants and on rare occasions described in a fetus *in utero* as stated by Barba & Freriks (1953) and by Bennett & Nelson (1953) Cases occurring after the age of 5 months are so rare that one should

partially due to the anemia In seven cases ESR was above 100 mm/1 h The calcium and phosphorus levels were normal Alkaline phosphatase levels were increased above 25 KA units up to 70 KA in 14 cases

*Table 3 Hemoglobin levels*

| Hemoglobin level in ge per cent | Number of cases |
|---|---|
| 11 and above | 3 |
| 11–9 | 14 |
| 9–6 8 | 12 |
| | 29 |

*Table 4 WBC distribution*

| WBC per mm³ | Number of cases |
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| 12 000 and lower | 11 |
| 12 000–20 000 | 9 |
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## DISCUSSION

The cause of infantile cortical hyperostosis is still disputed Familial occurrence has been described, as reported by Pajewski & Vure (1967), Holman (1961), Sidbury & Sidbury (1954), Tampas et al (1961), Veller & Laur (1953) and Barba & Freriks (1953), suggesting a possible hereditary factor Allergy to milk, high familial occurrence of asthma and good response of the disease to corticosteroids suggested an allergic background to the disease as put forward by Morrison (1957) and Bowman et al (1961) Seven cases in the present review, who developed swollen eyelids, conjunctivitis, also suggest an allergic background for this condition The recurrency rate in these cases was higher than in the other cases, and they responded well to steroid therapy Four children in this group developed allergic diseases, as found in the follow-up Negative cultures and serological tests eliminate infection as a causative factor Possibility of vitamin C deficiency or hypervitaminosis (vitamin A) was investigated and ruled out as a causative factor

The pathological changes of infantile cortical hyperostosis have been studied in a few cases by Dickson et al (1957), Eversole et al (1957),

gonivelocele, etc ), as observed by Thompson et al (1964) (Figure 6), closely resembles the final bony appearance of infantile cortical hyperostosis This suggests further clinical investigation to clarify the possibility of delay in myelinization in patients with infantile cortical hyperostosis Iron deficiency anemia was present in 26 out of 29 patients, and was severe in 12 of them The deficient nutrition (loss of appetite, vomiting fever) can not be the only reason for this anemia

Occasional residual complications of the disease, such as bony deformities synosthosis between the involved bones, persistent facial asymmetry and exophthalmus were reported by Caffey & Silverman (1945), Morrison (1957), Sherman & Hyllyer (1950), Scott (1963) and by Swedfoff et al (1970) There were no such complications observed in our cases

## SUMMARY

Twenty nine cases of infantile cortical hyperostosis with a wide range of bone involvement are reviewed Soft tissue painful swellings began before roentgenographic changes appeared in the underlying bone In 17 babies gradual involvement of different bones was noted In seven cases lesions previously healed became reactivated The disease is self-limiting and appears in a narrow age group Mandibular involvement is most common The clinical picture and laboratory data are reported Differential diagnosis and possible etiological factors are discussed The similarity of infantile cortical hyperostosis to extreme periosteal new bone formation in response to trauma in sensorily deprived children is suggested as a possible etiological factor

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*Figure 6 Extreme periosteal reaction following bilateral femoral epiphysiolysis in a 16 month old child with meningomyelocele*

question the diagnosis in a patient above this age The young age of the patients with infantile cortical hyperostosis, is probably due to a common predisposing factor This factor can be lack of maturity of the CNS and undeveloped myelinization of the peripheral nerves The myelinization is initiated during the fourth month of intra-uterine life and progresses in a more or less definite sequence until the fibers in which the process is latest to start, with few exceptions, show traces of myelin before the end of the third month of postnatal life The myelinization process continues to spread actively to new structures throughout the second year of postnatal life It is of interest that the trigeminal nerve, which gives the sensory supply around the mandible, is the last of the cranial nerves to start myelinization

Extreme and uncontrolled cortical thickening (and periosteal reaction) as a response to trauma in sensorily deprived children (menin-

Acta orthop scand 46 737–743 1975

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# MANAGEMENT OF FRACTURED SCAPHOID BONE

## *A Prospective Study of 100 Fractures*

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Accepted 27 v 75

Among the injuries of the carpal bones, the fracture of the scaphoid bone still presents a most interesting and demanding problem of management The frequency of non-union after this relatively frequent fracture remains at the 4 per cent level even in well controlled series (Bohler et al 1954) Many of the non unions are painful and prevent the patients from doing heavy manual work The risk of non-union has led to long immobilisation times According to Sir Reginald Watson-Jones (1955) 'nearly all fractures of this bone unite if the period of immobilisation is suitably prolonged ' Verdan (1954) advocated an above elbow plaster cast to avoid the shearing effects of pronation and supination on the fracture Razemon (1972) recommended early operative treatment for fractures of the middle third of the scaphoid

The aim of the present prospective study was to compare the two types of casts and to define the indications for operative treatment

### CLINICAL MATERIAL

The series consisted of 99 patients who were treated for 100 fractured carpal scaphoid bones between 1st January 1971 and 27th November 1972 Thirty patients with fractured tubercle of scaphoid two patients who had Colles fracture of the same wrist and one with perilunar transscaphoidal dislocation treated during the same period were excluded from the study Eighty four patients of the series were male and 15 were female The age range was 16 to 71 years (mean 31 years) The location type and displacement of the fractures are shown in Figures 1 and 2

### METHODS OF TREATMENT

By prior randomisation 53 fractures were immobilised in a plaster cast from below the elbow to the interphalangeal joint of the thumb (Figure 3) 47 fractures were

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*Key words* hyperostosis infantile

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Figure 3 *The below-elbow cast*

obscure fracture line in all projections Tomography and magnification films were found to be unnecessary Disappearance of tenderness in the snuff box appeared to be an important sign in corroborating the radiographic findings For the determination of complete bony union the radiograms were scrutinised retrospectively without knowing the type of treatment

Figure 4 *The above elbow cast*

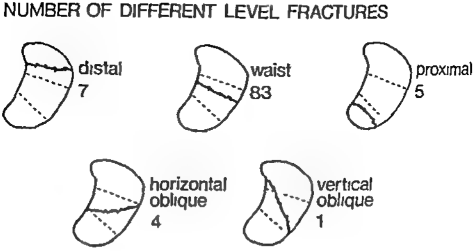


*Figure 1 Location of 100 scaphoid fractures*

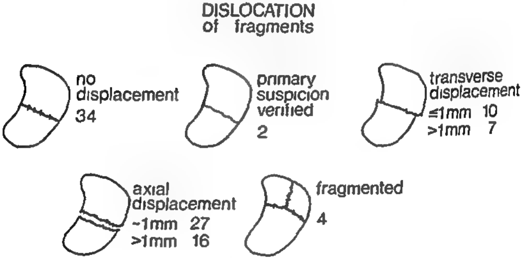


*Figure 2 Dislocation of fragments in 100 scaphoid fractures*

immobilised in an above-elbow cast, preventing pronation and supination but allowing extension and flexion of the elbow to some extent (Figure 4) To prevent elbow stiffness immobilisation in the above elbow plaster was changed to a below elbow type at 6 weeks when required (Verdan 1954)

The types and locations of the fractures in the two groups are presented in Table 1 The age distributions of the patients in the groups were similar Primary treatment was given by the registrars on duty Later the authors followed the patients until the end of management Every 2 weeks the cast was removed to clinically and radiographically check on the consolidation The patients were followed until they were symptomless or a steady state was achieved

The radiographic control used three exposures routinely, when required, three to six additional projections were taken Proceeding bony union was determined by

*Figure 3 The below elbow cast*

obscure fracture line in all projections Tomography and magnification films were found to be unnecessary Disappearance of tenderness in the snuff box appeared to be an important sign in corroborating the radiographic findings For the determination of complete bony union the radiograms were scrutinised retrospectively without knowing the type of treatment

*Figure 4 The above elbow cast*

*Table 1 Type and location of the scaphoid fracture in two treatment groups*

| Type or location | Below elbow cast | Above-elbow cast |
|---|---|---|
| No displacement | 18 | 18 |
| Transverse displacement | 10 | 7 |
| Axial displacement | 23 | 20 |
| Fragmented | 2 | 2 |
| Distal | 3 | 4 |
| Middle | 42 | 41 |
| Oblique | 4 | 1 |
| Proximal | 4 | 1 |

If consolidation was not achieved in 3 months osteosynthesis was performed using the technique of Gasser (1965) If necessary, the osteosynthesis was followed by immobilisation in a plaster slab for up to 6 weeks

## RESULTS

Ninety-two fractures united within 3 months, 41 fractures with the above-elbow plaster and 51 with the below-elbow plaster The average times of immobilisation and complete bony union are shown in Table 2 There were no statistically significant differences between the two treatment groups No differences were found between the two groups in achieving mobility after removal of the cast

*Table 2 Average immobilisation and consolidation times in non operatively treated fractures*

| | Below elbow cast | Above elbow cast |
|---|---|---|
| Immobilisation time | 48 days | 49 days |
| Complete radiographic consolidation | 58 days | 56 days |

As a sign of poor vascularisation, a relative density of the proximal fragment was observed in 24 cases (Figures 5 6 and 7) Eighteen of them were among the 92 non-operatively treated fractures (19 6 per cent) and six among the eight cases treated with osteosynthesis (75 per cent)

The time of consolidation was longest in the proximal fractures ($76 \pm 32$ days, mean $\pm$ s d ) A horizontal oblique fracture, a transverse

*Figure 5 Relative density of the proximal fragment after 4 weeks' immobilisation*

*Figure 6 As a sign of the beginning vascularisation the rarefaction is spreading into the proximal fragment (at 9 weeks)*

*Figure 7 Increasing rarefaction at 14 weeks, bony union is obvious*

displacement and a gap between the fragments also resulted in long immobilisation times (62 ± 24 days)

Among the non-operatively treated patients, the mobility of the elbow joint was practically normal 2 weeks after the end of immobilisation Radial deviation of the wrist averaged 67 per cent of normal after 2 weeks' mobilisation, while the other movements had returned to the 80 per cent level After 4 weeks' mobilisation, 29 patients had some

restriction of wrist movements The fist strength of the hand averaged more than 75 per cent of normal 25 days after the cast had been removed

Bony union did not occur within 3 months in eight cases whereafter an osteosynthesis was performed (two after the below elbow cast and six after the above elbow cast) In four cases no post operative immobilisation was used The screw was removed in six cases due to slight continuous pain

## DISCUSSION AND CONCLUSIONS

Non-operative treatment of the carpal scaphoid results in a certain frequency of non-unions which cannot be totally prevented even with a 3 month immobilisation time Based on cadaver studies, Verdan (1954) proposed an above-elbow plaster to diminish the rotational stresses upon the fracture Theoretically, the fixed elbow may even increase the shearing forces at the fracture site when the hand meets some obstacle and is passively rotated

We planned our study to determine whether longer casts really improve bony union Wearing a below elbow cast, the patients are able to continue many activities not requiring strength, while the above elbow cast makes life inconvenient In our study of 100 fractured scaphoids, 92 per cent of the fractures united within 7 weeks and no difference was found between the two plaster groups The limit of delayed union was set at 3 months Eight fractures, which were not united at that time, were fixed with a screw (Gasser 1965) After this procedure, these fractures united

It may be advisable to try to foresee the fractures which will not unite within a reasonable time In accordance with Maudsley & Chen (1972) we have begun to operate primarily on the fractures with severe dislocation One might also consider an early operation in the case of a fracture with a small, relatively dense proximal fragment On the basis of eight cases we do not suggest that the screw fixation totally solves the problem of non-union

In conclusion, the traditional below elbow cast gives adequate immobilisation for the scaphoid fracture Long immobilisation times over 3 months, may be prevented by osteosynthesis

SUMMARY

One hundred fractured carpal scaphoids were immobilised alternatively in above elbow and below elbow casts Preventing the pronation and supination of the forearm did not reduce the immobilisation time, which with either type of cast, averaged 7 weeks, after exclusion of the fractures with delayed union These eight fractures, which did not unite in 3 months, were operated on using a lag screw fixation, whereafter consolidation was achieved

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restriction of wrist movements The fist strength of the hand averaged more than 75 per cent of normal 25 days after the cast had been removed

Bony union did not occur within 3 months in eight cases whereafter an osteosynthesis was performed (two after the below-elbow cast and six after the above-elbow cast). In four cases no post operative immobilisation was used The screw was removed in six cases due to slight continuous pain

## DISCUSSION AND CONCLUSIONS

Non-operative treatment of the carpal scaphoid results in a certain frequency of non-unions which cannot be totally prevented even with a 6-month immobilisation time Based on cadaver studies, Verdan (1954) proposed an above-elbow plaster to diminish the rotational stresses upon the fracture Theoretically, the fixed elbow may even increase the shearing forces at the fracture site when the hand meets some obstacle and is passively rotated

We planned our study to determine whether longer casts really improve bony union Wearing a below-elbow cast, the patients are able to continue many activities not requiring strength, while the above elbow cast makes life inconvenient In our study of 100 fractured scaphoids, 92 per cent of the fractures united within 7 weeks and no difference was found between the two plaster groups The limit of delayed union was set at 3 months Eight fractures, which were not united at that time, were fixed with a screw (Gasser 1965) After this procedure, these fractures united

It may be advisable to try to foresee the fractures which will not unite within a reasonable time In accordance with Maudsley & Chen (1972) we have begun to operate primarily on the fractures with severe dislocation One might also consider an early operation in the case of a fracture with a small, relatively dense proximal fragment On the basis of eight cases we do not suggest that the screw fixation totally solves the problem of non-union

In conclusion, the traditional below elbow cast gives adequate immobilisation for the scaphoid fracture Long immobilisation times, over 3 months, may be prevented by osteosynthesis

*Table 1*

| | Male | Female | Total |
|---|---|---|---|
| Number of patients | 30 | 54 | 84 |
| Number of elbows | 37 | 68 | 105 |

| | |
|---|---|
| Right side | [illegible] patients |
| Left side | 22 patients |
| Both sides | 21 patients |
| | 84 patients = 105 elbows |

| | |
|---|---|
| Mean age at operation | 46 (16–65) years |
| Mean duration of rheumatoid arthritis | 17 years |
| Mean duration in elbow | 9 years |
| Mean observation time | $3\frac{3}{4}$ ($1\frac{1}{4}$–$6\frac{3}{4}$) years |

rotation) were the main indications The pain was graded as severe moderate, or none and was registered both at work and at rest

*Technique of operation*

The operation was usually performed under regional anaesthesia with a pneumatic cuff All operations were performed in the following way radial approach the capsule and collateral ligament were split longitudinally and detached from the supracondylar ridge of the humerus in continuity with periosteum The head of the radius was excised in all cases This permitted wide access to all aspects of the joint including the posterior recess When the joint had been cleared of synovium (much is to be found around the neck of the radius), the capsule and the lateral ligament were sutured with silk around the drain, and the skin closed No external fixation was made The drain was removed after 24 hours, and active and passive exercises started Some of the patients left the hospital 2 days after surgery but most stayed longer

*Complications*

We had one radial nerve palsy completely restored after 6 months one haematoma and one superficial infection These three patients were all very satisfied at follow-up One patient had a wound rupture on the 11th day After resuture, superficial infection developed and the patient was dissatisfied at follow up because of pain during movement

## RESULTS

Results were assessed on the basis of the patient's own opinion, the severity of any residual pain, changes in the range of movement, signs of recurrent synovitis and instability, and X-ray findings

Acta orthop scand 46 744–750 1975

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# SYNOVECTOMY OF THE ELBOW IN RHEUMATOID ARTHRITIS

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Accepted 25 iii 75

In view of the fact that Porter and his collaborators (1974) reported that in a hospital population suffering from rheumatoid arthritis 25 per cent of the cases had severe disability in the upper extremities resulting totally or partly from disease of the elbow and that only 28 per cent showed no clinical evidence of elbow involvement, it is astonishing how little has been written concerning surgery of the elbow in rheumatoid arthritis Since the elbow joint is not as heavily burdened as the knee joint, symptoms of synovitis in its early stages are not as pronounced there as in the knee

In our clinic, synovectomy of the elbow is a frequent operation and we believed it would be of interest to make a follow up study of a patient material which was homogeneous and where the surgical technique was standardized

## MATERIAL AND METHODS

### *Clinical material*

During the period 1965–1971 synovectomy was performed on 118 elbows in 91 patients at the Department of Orthopaedic Surgery in Lund All of the patients had classical or definite rheumatoid arthritis Eight patients (13 elbows) were excluded from the follow up (five had died and three were not found) but three patients (four elbows) are included who at follow up were already re operated (arthroplasty) The latter four elbows are classified as failures During the period of this study, arthroplasty was not performed as the first operation the small operation (synovectomy + resection of the radial head) was always undertaken as a first trial Details concerning the patients are given in Table 1

The main indication for operation was pain In a few cases the presence of a persistent synovitis and/or progressive joint stiffness or loss of movement (mainly

This investigation was financially supported by Alfred Österlunds Stiftelse Riksföreningen mot Rheumatism and Stiftelsen Konsul Thure Carlssons Minne

*Table 5 Reasons given by 20 patients for being dissatisfied (some patients gave more than one reason*

| | |
|---|---|
| Swelling with pain | 5 |
| Swelling with pain ulnar side only | 3 |
| Pain without swelling | 11 |
| Pain with weakness | 4 |
| Rotation movement less | 4 |
| Hinge movement less | 5 |

*Table 6 Reoperated elbows of 20 dissatisfied patients and preliminary results*

| | Result |
|---|---|
| Ulnar synovectomy + transposition of the ulnar nerve | 2 good |
| Trimming proximal end of the radius + resynovectomy (bad surgical technique) | 2 good |
| Resection of the ulnar head | 2 good |
| Interposition arthroplasty | 4 good |
| Hinge prosthesis | 3 2 good 1 infect |
| (No reoperation 7 elbows) | 13 |

to the following scale based on that of Steinbrocker et al (1949) Grade I = osteoporosis and soft tissue changes only Grade II = mild or moderate degree of erosive change mild or moderate reduction of joint space Grade III = joint space markedly narrowed (to less than 1 mm) and more extensive erosions Grade IV = subluxation, no joint space bad deformation of the radial head Six elbows have passed from Grade II to Grade III and three of these patients are dissatisfied Ten elbows have passed from Grade III to Grade IV (five are dissatisfied), and for twelve elbows where the preoperative grade was IV the patients are dissatisfied

Twelve patients with 20 elbows are dissatisfied and the patients' reasons for being dissatisfied are shown in Table 5 Thirteen of these 20 elbows were reoperated The reoperations are shown in Table 6

## DISCUSSION

Assessment of the results of synovectomy in rheumatoid arthritis has many problems In the upper limb it is particularly difficult to evaluate the function of a single joint in a patient suffering from polyarticular disease

*Table 2 Pain before and after surgery, 105 elbows*

| | Constantly | | Occasionally | | Never | | Less than preoperatively |
|---|---|---|---|---|---|---|---|
| | Preop | Postop | Preop | Postop | Preop | Postop | |
| Pain at rest | 80 | 14 | 25 | 62 | 0 | 29 | 91 = 87 % |
| Pain at work | 102 | 40 | 3 | 51 | 0 | 14 | 80 = 78 % |

*Table 3 Hinge and rotation movement after surgery, 105 elbows*

| | Hinge | Rotation |
|---|---|---|
| Gain | 40 | 63 |
| Same within ± 10° | 55 | 32 |
| Loss | 10 | 10 |

*Table 4 Pre and postoperative X-ray grading of elbows (see text)*

| Grade | Preop | Postop | Preop grade of 20 elbows in dissatisfied patients |
|---|---|---|---|
| I | 0 | 0 | |
| II | 26 | 20 | 3 |
| III | 62 | 58 | 5 |
| IV | 17 | 27 | 12 |
| | 105 | 105 | 20 |

*Patient's own opinion* 72 patients with 85 operated elbows were satisfied with the operation at follow-up That means 81 per cent satisfaction (calculated per elbow)

*Pain* Relief of pain was good, as seen in Table 2, 78 per cent had less pain at work and 87 per cent had less pain at rest

*Mobility* Hinge and rotation movements were maintained or improved in most of the joints (Table 3)

*Stability* No patient complained of symptoms which could be attributed to joint instability

*Recurrent synovitis* Eight patients had swelling with pain and three of these had symptoms on the ulnar side only

*Radiological findings* are shown in Table 4 The pre- and postoperative AP and lateral radiographs of each elbow were assessed and an overall radiological grade of disease severity was assigned according

we performed only seven arthroplasties (four interpositions · three hinges), in all cases we performed synovectomy + radial hand resection as a first step We think that this fact strongly argues in favour of "the small operation,' which is easily done, demands very little postoperative treatment, and, with few complications, helps about 90 per cent of patients with the most usual and worst symptom, viz, pain at rest We believe that examination of the elbows should be routine in the case of all rheumatic patients, including especially palpation of the head of the radius and assessment of pain and crepitation by pro- and supination movements We believe that many arthroplasties could be avoided if synovectomy + resection of the radial head were undertaken at an early stage We find that the radial incision is sufficient in most cases, to add an ulnar incision no doubt causes more extensive operative trauma in the joint, with stiffness and difficulty in regaining the preoperative range of movement


## SUMMARY

The results of 105 synovectomies + resection of the radial head in 84 patients with rheumatoid arthritis are shown Pain was the main indication for surgery, and $1^1/_4$ $6^2/_4$ years later about 80 per cent had pain relief at work 90 per cent pain relief at rest About 60 per cent of the elbows gained in rotation movement about 40 per cent gained in hinge movement Thirteen elbows had to be reoperated In all cases there was only radial approach to the joint, which the authors find gives adequate exposure, few complications, and easy postoperative treatment


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To show if synovectomy has a preventive effect, meaning that it stops the disease in the elbow, a prospective study must be made on elbows belonging to Grade I To make a reasonably complete synovectomy we consider it necessary to resect the radial head, but as this resection gives symptoms in the distal radio-ulnar joint in about 50 per cent of patients not suffering from rheumatoid arthritis (Taylor & O'Connor 1964), we, like Porter et al (1974), do not think that this resection is acceptable in a purely prophylactic operation

Published reports on follow-up investigations of synovectomy of the elbow, with few exceptions, cover only limited and heterogeneous material: Wilkinson & Lowry (1965), Merle d'Aubigne & Delbarre (1969), Torgerson & Leach (1970), Saltzer & Schwagerl (1970), Inglis et al (1971) and Marmor (1972)

Wilson et al (1973) reported on 55 elbows in 46 patients with good pain relief in about 90 per cent, but the surgical technique is not uniform in their material sometimes they made two incisions, sometimes they resected the radial head

Porter et al (1974) reported on 123 patients with 154 elbows, about 50 per cent of which were classified as Grade III on the Steinbrocher X ray scale The first 62 elbows were operated through a radial incision, but in the last 92 elbows two incisions were made According to Porter et al (1974), surgery gives noticeable pain relief in about 70 per cent of the cases, whereas range of movement is not affected to any great degree Cases operated with two incisions showed better results, but here the observation time was shorter

In our series we obtained noticeable pain relief at rest in about 90 per cent of the elbows and at work in about 80 per cent (Table 2), and these results are slightly better than those of Porter et al (1974) and about the same as those reported by Wilson et al (1973) In 60 per cent of our cases there was a gain in rotation movement and, what surprised us, in 38 per cent there was a gain in hinge movement This may be caused mainly by resection of the often badly deformed radial head, which was a mechanical hindrance to movement, but also by pain relief The ten patients who lost in hinge movement were the same who lost in rotation

In our series, no patient complained of symptoms which could be attributed to joint instability Porter et al (1974) found the same and this may be explained by the fact that a joint with less pain than before seems stronger to the patient

During the period covered by the present investigation (1965–1971)

Acta orthop scand 46 751–757 1975

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# SURGICAL TREATMENT OF RUPTURE OF THE ROTATOR CUFF TENDON

GEORG BAKALIM & MANU PASILA

Accepted 12 v 75

Rupture of the rotator cuff tendon still constitutes a therapeutic problem although surgical repair of this lesion was introduced in the beginning of this century (Codman 1934) This tendon tear differs from others in that operative treatment is not always considered a matter-of course Gratifying results are sometimes obtained with con servative therapy and initially it is difficult to select the cases in which surgery would be the method of choice However, it may be assumed that the best results are obtained by operations performed soon after injury as is generally the case in tendon ruptures

## MATERIAL AND METHOD

The series followed up consists of 55 patients with arthrographically verified rupture of the rotator cuff tendon surgically treated at the Department of Orthopaedics and Traumatology Helsinki University Central Hospital during the period 1960–1970 (Bakalim & Pasila 1973) Only three patients were under 40 years of age 11 were 40–49 years old 34 were 50–59 and seven were over [illegible] years The age distribution of the patients is similar to that for osteo arthritis It may be mentioned that of 193 patients with ruptures of the rotator cuff tendon treated at the Physical Department of our hosp tal from 1960–1965 only 24 (12 per cent) were operated upon (Pasila 1965) The majority of the present surgically treated pat ents were labourers performing heavy work, who did not progress satisfactorily by physiotherapy The operation was performed within 3 months of injury in over half the cases (30/55) and within half a year [illegible] 43/55 cases (Table 1) Only 12/55 tears were treated surgically more than half a year after the accident The indica t ons for surgery were painful weakness of the shoulder joint and nocturnal pain A pre requisite for surgery was full passive abduction

Operative repair of the rotator cuff tendon was carried out in practically all recent ruptures (time lapse between rupture and operation less than 6 months)

In connection w th operative repair partial excision of the acromion was performed in 20 first-operated cases in order to facilitate the postoperative

Torgerson, W R & Leach, R E (1970) Synovectomy of the elbow in rheumatoid arthritis *J Bone Jt Surg* 52 A, 371

Wilkinson, M C & Lowry, J H (1965) Synovectomy for rheumatoid arthritis *J Bone Jt Surg* 47 B, 482

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*Key words* surgery, elbow, synovectomy, rheumatoid arthritis, radial head

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ACTIVE ABDUCTION OF THE SHOULDER JOINT

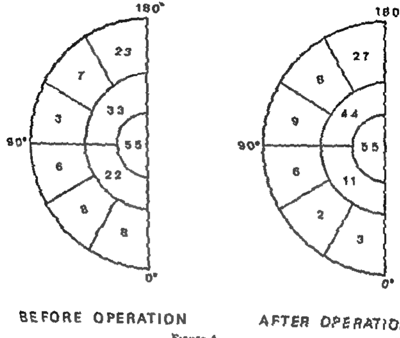


*Figure 1*

*Table 1 Time lapse between accident and operation*

| Time from accident to operation | No of patients |
|---|---|
| < 1 month | 7 |
| 1 3 months | 23 |
| 3 6 months | 13 |
| 6-12 months | 3 |
| >12 months | 9 |
| Total | 55 |

served in connection with partial excision of the acromion Of the patients on whom excision of the acromion was performed either alone or in connection with operative repair, eight showed impairment of the range of active abduction By contrast active abduction decreased in only one out of 19 patients treated by operative repair alone

In labourers performing heavy work, the return to work may be

mobilization of the shoulder joint Excision of the acromion allowed the possibility of reaching a far retracted rupture margin Later the excision of the acromion was abandoned because of the untoward effect mentioned in the results

Excision of the acromion alone was the only procedure carried out in 16/55 patients, as this was the treatment of choice when the time lapse from the accident exceeded half a year (10/12) In more recent ruptures this operation alone was carried out occasionally in small ruptures when the width of the tear was less than 2 cm (6/40).

The rupture was complete in all operated cases and usually was transversal In a few cases the rupture also involved part or all of the infraspinatus The supra spinatus tendon was generally retracted, the margin usually frayed and thickened The width of the tear was measured at the operation and classified as small or large depending on whether it was smaller or larger than 2 cm There were 32 small and 23 large tears The bursa subacromialis and subdeltoidea often were obliterated No calcium deposits were observed No large osteo arthritic changes could be demonstrated Sometimes it was difficult to distinguish previous osteo arthritic changes from secondary post-traumatic changes

The rotator cuff repair was performed either according to the McLaughlin method (1962) or a bilateral incision was made to permit suturing the refreshened tendon brim through burr holes in the bone along a groove chiselled cranially in the greater tubercle

## RESULTS

Postoperatively the patients were followed up for at least 1 year or until they were definitely able to resume working

The results of surgery are illustrated by the change in active abduction of the shoulder joint as shown in the diagrams in Figure 1, the first of which represents the state just before operation and the second the final range of abduction attained after operation The latter diagram shows that active abduction was permanently impaired in some cases As was to be expected, active abduction was more limited preoperatively in the patients with large ruptures

A patient treated by partial excision of the acromion more than half a year after the accident had preoperatively had a normal range of active abduction despite having a total avulsion of the whole rotator cuff tendon After complete excision of the acromion without cuff repair, the head of the humerus was dislocated upwards to such an extent that active abduction was under 30 degrees at follow-up examination 3 years post-operatively, although passive abduction was normal Owing to the extent of the tear, the acromion had been necessary to prevent upward dislocation of the head of the humerus during active abduction

The same tendency towards impaired abduction was frequently ob-

recovery takes several months, even after conservative treatment, surgery makes no appreciable difference in this respect Codman (1934) recommended surgical intervention soon after the accident Heikel (1968) found excellent and good results after early surgical repair A delay of about a month, during which time physical therapy is given, has been considered to cause no harm (McLaughlin 1962) Operative treatment is recommended when good abduction is not restored by conservative treatment for 1–1½ months (Da Palma 1950), 2–4 months (Campbell 1963), 4–6 months (Debeyre et al 1965)

Adams (1964) and Magnusson (1959) recommended against operative treatment of patients over 40 years of age In the present material only three patients were under 40 The age distribution was similar to that for osteo-arthritis The significance of degenerative changes in the aetiology of ruptures in the rotator cuff tendon is generally accepted (McLaughlin 1944, 1962, Olsson 1953, Magnusson 1959, Bunnell 1959) In our series the degenerative changes found at operation were not very predominant No large osteo arthritic changes and no calcification were demonstrated Perhaps the traumatic origin is more dominant in our operated patients

According to Bunnell (1959), removal of a portion of acromion can be done if it blocks abduction Excision of the acromion allows the possibility of reaching a far retracted rupture margin A tendency toward impaired abduction was frequently observed after excision of the acromion either alone or in connection with operative repair of the tear Active abduction decreased in only one patient treated by operative repair alone In the case of a large rupture, excision of the acromion cannot be recommended as the only procedure carried out, because the acromion is necessary to prevent upward dislocation of the head of the humerus in abduction An untoward effect of excision of the acromion was observed after operative repair of a tear when the [illegible]

A [illegible]

[illegible] excision of the acromion, gave unsatisfactory results because without rotator cuff integrity the intact acromion was important to the shoulder

Excision of the acromion alone is adequate in selected cases, when surgical treatment is resorted to a long time after the accident It may be recommended for treating small tears in patients with satisfactory abduction strength, especially if the painful arc symptom is not relieved

considered the criterion of a successful operation Half the labourers (23/44) were able to return to their previous work (Table 2) Postoperatively they were not able to work for at least [illegible] months Of the patients who still had not returned to work half a year after the operation, very few returned later (2/23) All patients operated upon within 1 month of the accident returned to their previous work

*Table 2 Unfitness for work and return to heavy work*

| Months | Duration of unfitness for work 3 | 3–6 | 6–9 | Total |
|---|---|---|---|---|
| Returned | 11 | 10 | 2 | 23 |
| Not returned | | | | 21 |
| Total | | | | 44 |

*Table 3 Return to heavy work related to width of the rupture*

| Width of rupture | Return to work | Unfit for work | Total |
|---|---|---|---|
| Small ruptures | 13 | 12 | 25 |
| Large ruptures > 2 cm | 10 | 9 | 19 |
| Total | 23 | 21 | 44 |

The extent of the tear did not seem to influence the return to heavy work (Table 3)

Independently of the extent of the resection, excision of the acromion brought immediate relief of nocturnal pain

## DISCUSSION

A tear of the rotator cuff tendon was operatively treated within [illegible] month of the accident in four labourers performing heavy work All of them returned to their previous work This group is too small to permit any further conclusions but it seems evident that operative repair ought to be considered immediately after injury if the clinical symptoms are severe enough This would include some patients who also might recover after conservative therapy but considering that

Olsson [illegible] (1953) Degenerative changes of the shoulder joint and their connection with shoulder pain *Acta chir scand* Suppl 181
Da Palma A F (1950) *Surgery of the shoulder* J P Lippincott Company Philadelphia
Pasila M (1965) Periarthritis glenohumeralis *Duodecim* Suppl 44

*Key words* rotator cuff tears operative treatment

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by any other means Excision of the acromion brings relief of nocturnal pain in patients with rupture of the rotator cuff tendon

Labourers performing heavy work with a torn rotator cuff often are incapacitated for work even after successful operative treatment of the lesion

## SUMMARY

A total of 55 tears of the rotator cuff tendon were surgically treated at the Department of Orthopaedics and Traumatology, Helsinki University Central Hospital, during the period 1960 1970 The rate of operative treatment was about 12 per cent When more than half a year had elapsed since the accident, excision of the acromion was almost the only operative procedure carried out (10/12 patients) Excision of the acromion was performed as the only procedure in 16 cases and in connection with surgical repair of the rotator cuff tendon in 20 cases This operation brings relief of nocturnal pain, but it is harmful in the treatment of large tears when used alone and sometimes also in connection with surgical repair of the rotator cuff tendon Surgical repair of the lesion seems to give the best results provided it is performed *within 1 month of the injury*

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Acta orthop scand 46 758–763, 1975

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# FRACTURE OF THE SCAPULAR NOTCH ASSOCIATED WITH LESION OF THE SUPRASCAPULAR NERVE

H G Edeland & B E Zachrisson

*Accepted 20 v 75*

Fractures of the scapula are not common Due to the muscular coverage and the ability of this bone to glide and recoil in relation to the chest wall, considerable violence is needed to cause the fracture The scapula fracture is generally one among other injuries caused by a serious trauma, often a crush injury In a comprehensive study Rowe (1963) found fractures of the scapula to have occurred in 54 out of 1,603 injuries of the shoulder girdle According to DeCoulx et al (1956) the fractures of the scapula may be classified anatomically in three groups I Fractures of the body, II Fractures of the apophysis, III Fractures through the superior lateral angle In the latter type the scapular notch may be involved by the fracture

## *Anatomy*

The scapular notch (incisura scapulae) of the superior lateral angle of the scapula is of varying dimensions and shapes but most often forms an approximately 2 cm deep, 1 cm wide 'bay' of the scapula bone (Figure 1) Laterally the incisure is bordered by the base of the coracoid process The incisure carries the mixed sensory and motor suprascapular nerve on its way from the brachial plexus to the shoulder girdle The nerve originates from the fourth fifth and sixth cervical nerves After passage through the scapular notch it ramifies to the supraspinatus and infraspinatus muscles to parts of the acromioclavicular and humeroscapular joints, and to the scapula itself The notch is bridged at its entrance by a thick, well vascularized ligamentous structure (lig transversum scapulae) with deviations carrying vessels and nerves to the lateral parts of the clavicula and to the acromion (Moseley 1969)


*Figure 1 Scapula specimen in antero posterior projection a) The central X ray beam is vertical to the body b) The tube is angled 30° caudally In this projection the scapular notch (→) is fully visualized while in a) the scapular spine is projected over the notch*

## *Purpose of the study*

The hypothesis initiating and guiding this study was that residual disability following a scapula fracture might be due to a lesion of the suprascapular nerve on its passage through the scapular notch This hypothesis is in part supported by the effect of the suprascapular nerve block, obtained by infiltration of local anaesthetics at the notch (Bonica 1953 Gordh 1969 Edeland & Stefansson 1973) but is contradicted by the reported absence of any loss of shoulder or upper-arm muscle strength in a group consisting of 28 patients, all with type III scapula fractures (Zdravkovic & Damholt 1974) Hence, the purpose of the present investigation was to search for correlated scapular nerve lesions in patients having sustained scapula fracture with scapular notch involvement

## MATERIAL AND METHODS

During a 21 month period (1972 1973) fractures of the scapula were found in 18 patients 15 males and 3 females) examined at the Roentgendiagnostic Department I I the Sahlgren Hospital in Gothenburg Sweden All patients were treated non operatively and were re examined clinically Of the 18 patients 11 did not complain of any residual shoulder girdle functional losses Seven of the 18 patients who had subjective symptoms were also re examined roentgenologically with a minimum follow up time of 1 5 months and maximum follow up time of 23 months (mean 10 months)

The roentgenograms from the primary 18 examinations consisted of conventional antero-posterior and lateral projections (Clark 1973, Fritz & Kohler 1968) The films were reviewed regarding the type of scapular fracture At the re examinations the scapular notch was examined by an antero posterior projection with the tube angled approximately 15°–30° caudally This tube angle was chosen after a primary study of scapula specimens in different antero posterior projections (Figure 1) In order to avoid interference with the thoracic wall structures the patients were told to extend the arm laterally and cranially TV-monitored positioning was found to considerably facilitate the examination

In four of the patients there were reasons—arm abduction and outward rotation weakness, and/or fracture location—to include an electromyographic examination (EMG) of the supraspinatus muscle (Basmajian 1967, Kendall et al 1971) in the follow up examination The EMG was evaluated according to a conventional clinical electromyographic method Coaxial needle electrodes were employed Duration and amplitude as well as the number of phases of the individual motor unit potentials were assessed on the screen of the oscilloscope

## RESULTS

Three of the 18 fractures of the scapula were located at the lateral angle of the scapula (type III according to the classification of DeCoulx et al 1956) In two of these cases the scapular notch was involved by the fracture The radiologically re examined seven cases had healed or showed progressing healing

By conventional X ray technique with antero-posterior and lateral projections the scapular notch was visualized in only three of the 18 cases, while antero-posterior projection with the tube angled approximately 15°–30° caudally in all the re-examined seven cases gave a clear visualization of the scapular notch

All seven patients with subjective symptoms were found to have a reduced supraspinatus function One of the four patients examined with EMG showed obvious signs of suprascapular nerve involvement, as judged by physical examination, roentgenologically primarily derangement of the entire supraspinous fossa and fracture of the surgical neck of the scapula (Figure 2a) and pathological EMG findings The patient had been injured in a traffic accident more than 1½ years prior to the re-examination The patient had not experienced any functional improvement—or impairment—during the year prior to the follow-up examination At the follow-up examination the supraspinatus muscle was found to have considerably reduced volume and strength The roentgenograms from the follow-up revealed a callus encroachment of the scapular notch (Figure 2b) EMG performed 5 months thereafter showed partial restitution (Figure 3)

*Figure 2 a Fresh comminuted grade III scapula fracture*

*Figure 2 b The same region 1½ years later Note the callus contouring of the scapular notch (→)*

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suprascapular nerve function is of value in the determination of the nerve injury A suprascapular nerve decompression operation could be considered in these cases


## SUMMARY

In a material consisting of 18 patients with scapula fractures, the scapular notch was involved in two cases In one of these cases injury of the suprascapular nerve function was proved The value of X-ray examination with projections visualizing the scapular notch is pointed out EMG examination in selected cases with the combination of reduced supraspinatus muscle function and a fracture of the scapular notch [illegible] recommended in order to diagnose injury of the suprascapular nerve


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*Key words* shoulder fractures (diagnosis/complications) scapula (injuries/radiography) peripheral nerves nerve compression syndromes radiography


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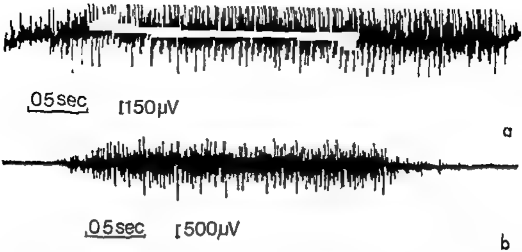


*Figure 3 EMG s of the supraspinatus muscle of the same patient as illustrated in Figure 2 The two pictures show signs of lesion of the peripheral motor neurone more evident on the first examination (a) than on the re examination (b) performed 5 months after the first examination*

## DISCUSSION

Fractures through the superior lateral angle of the scapula (type III, according to the classification of DeCoulx et al 1956) might involve the scapular notch There are obviously reasons to consider the presence of injury to the suprascapular nerve in these cases

The suspicion of a suprascapular nerve lesion in the patient referred to above was not raised until the primary roentgenograms were compared with those from the re-examination The physical examination and the EMG confirmed the diagnosis of nerve injury The material is, however, too small to draw any conclusions of the frequency of damage to the suprascapular nerve in fractures involving the scapular notch

According to this material the conventional X-ray examination of the scapula seems, in most cases, to be insufficient for visualizing the scapular notch, at least in the presence of a scapula fracture Pain and the general condition of patients who have recently sustained fractures of the scapula may prohibit more than only a screening examination of the prevailing fractures It is, however, recommended that the simple, (from caudal) angled antero posterior projections described above should be routinely included in the X-ray examination of patients with scapula fracture, type III

In cases with reduced supraspinatus muscle strength following scapula fracture involving the scapular notch EMG examination of the

thesis in 18. Neither routine anticoagulants nor prophylactic local or systemic antibiotics were used.

A follow up study (including clinical and roentgenological examinations) was possible in 60 patients with a mean observation time of 4.9 years. A total of 103 patients had died by the time of the survey while six patients had moved away.

## RESULTS

*Mortality.* 36 patients (21.3 per cent) died within 3 months of the operation. The life table (Figure 1) demonstrates that the mortality in this series parallels that of a normal population of the same age and sex apart from the immediate high mortality following the trauma.

Besides this we found the high primary mortality rate to be due mainly to a high incidence of complicating illnesses preoperatively. A total of 76 of the patients (45 per cent) were suffering from major cardiopulmonary or cerebrovascular disorders.

*General postoperative complications* were found in 67 patients as

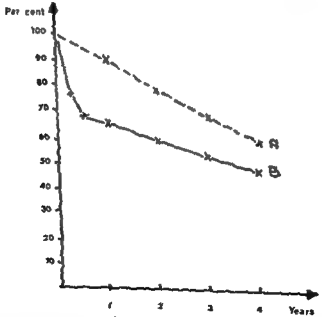


*Figure 1. Life tables.*
*A. Normal population of same age and sex distribution as the patient material (according to experiences of mortality in the period 1956–60 in Denmark).*
*B. For the 154 patients with definite information about survival time.*

Acta orthop. scand. 46, 764–774, 1975

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# A LONG TERM FOLLOW-UP OF MOORE ARTHROPLASTY IN FEMORAL NECK FRACTURES

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Accepted 28.ii.75

*In 1943 Austin Moore presented his first metallic hip prosthesis (Moore & Bohlman 1943). Fourteen years later he reviewed a series of patients treated for various conditions with his new self-locking hip prosthesis (Moore 1957).*

*During the past 20 years experience has shown the Austin Moore arthroplasty to be an acceptable method for the treatment of femoral neck fractures (Furey et al. 1961, Hinchey & Day 1964, King et al. 1959, Mayo 1961). Long term follow-up studies are still rather few, however (Andersson et al. 1964, Andersson & Nielsen 1972, Barr et al. 1964, Danielsson 1965, Golden 1969, Hinchey & Day 1964, Jansen & Ruben Hansen 1965, Mayer & Sarkar 1964, Polyzoides 1971, Salvati & Wilson 1973, Whittaker et al. 1972), and the long term prognosis needs further evaluation.*

*The present study analyses the long term results for a period of from 2.5 to 10 years in 60 patients.*

## MATERIALS AND METHODS

During the period 1963 to 1969 arthroplasty was performed for femoral neck fractures in 169 cases. Of these patients 142 were females (84.0 per cent) and the average age was 77.2 years. 121 patients (71.6 per cent) being more than 75 years of age.

The operative procedure used was according to the instructions given by Austin Moore in 1957. Acrylic cement was not used. The prostheses were all of the short stem type.

The arthroplasty was chosen as a primary operation in elderly patients only. Younger patients were treated with osteosynthesis. Physiological rather than chronological age determined the type of procedure to be employed. According to this Moore arthroplasty was the primary operation in 140 patients, while unsuccessful conservative treatment was the indication in 11 patients and failure of osteosyn

*Table 3 Settling—Osteolysis along prosthesis*

| | Normal X ray | Osteolysis along prosthesis |
|---|---|---|
| Settling 0–20 mm | [illegible] | 2 |
| Settling >20 mm | 4 | 11 |

Settling of the prosthesis was found in 29 cases (48 [illegible] per cent) In 15 patients this amounted to more than 20 mm As shown in Table 3 settling was significantly ($P < 0.001$) correlated to the existence of osteolysis along the prosthesis, while settling was significantly ($P < 0.001$) diminished in cases of marked ossification in the prosthetic fenestres (Table 4)

*Clinical follow up* Three decisive factors determine the final result They are pain mobility of the hip joint and walking capacity (Table 5)

Statistical analysis ($\chi^2$ test) of our results revealed no significant correlation between pain and the roentgenological finding of pre existing coxarthrosis minor peroperative fractures of the femoral neck, short length of the femoral neck, calcification in the soft tissues sclerosis along the prosthetic stem or migration of the prosthetic head Hip mobility was not significantly correlated to any of these roentgenological findings either

Reduced hip mobility however, correlated significantly ($P < 0.05$) to osteolysis along the prosthesis (Table 6) and to settling of the prosthesis of more than 20 mm (Table 7)

Contractures of the hip joint were encountered in 19 patients (31 7 per cent) Mainly flexion or external rotation contractures were seen They all amounted to a few degrees only and did not affect activity Contractures were not significantly correlated either to pain or to roentgenological changes The existence of contractures was not significantly related to disablement caused by other diseases either Walking capacity was significantly impaired in cases of insufficiency of the

*Table 4 Settling—Ossification in prosthetic fenestres*

| | No visible ossification | Marked ossification |
|---|---|---|
| Settling [illegible] 20 mm | 11 | 34 |
| Settling >20 mm | 12 | 3 |

Ossification clearly visible bone formation in fenestres

*Table 1 General postoperative complications in 67 out of 169 patients (39 6 per cent)*

| | |
|---|---|
| Cardio pulmonary diseases | 29 |
| Phlebo thrombosis | 16 |
| Pulmonary embolism | 11 |
| Acute arterial occlusion | 2 |
| Cerebral diseases | 3 |
| Prolonged fever | 5 |
| Decubitus ulcer | 11 |
| Miscellaneous | [illegible] |

listed in Table 1 (Included are only those of real severity ) Of the eleven patients with pulmonary embolism, this was fatal in five

*Local complications* following surgery are shown in Table 2

Wound infection healed in all eight cases The prosthesis was removed in two of the five patients with osteitis, whereas three died with persisting infection (but not as a result of it)

Besides these complications, two patients suffered spiral trochanteric fractures and three patients developed diaphyseal femoral fractures at the tip of the prosthetic stem In all but one of these cases a new relevant trauma caused the fracture

*Roentgenological findings* at follow-up Osteolysis at the tip of the prosthetic stem was seen in six cases, but in no case had the stem penetrated through the cortical bone In seven cases osteolysis was found along the whole prosthetic stem In five of these there was, however, marked ossification in the fenestres of the prosthesis Thus only two were classified as loose prosthesis Calcification in the soft tissues around the head of the prosthesis was a common finding (26 cases = 43 3 per cent)

Migration of the prosthetic head was encountered in ten cases (16 7 per cent) —in five of these migration amounted to more than 15 mm Protrusion through the acetabular roof was not seen in any case

*Table 2 Local complications in 37 out of 169 patients (21 9 per cent)*

| | |
|---|---|
| Minor femoral neck fractures | 17 |
| Failure of prosthetic position | 2 |
| Dislocation of the hip | 1 |
| Wound infection | 8 |
| Osteitis | 5 |
| Peroneal paralysis | 4 |

*Table 6 Reduced hip mobility—Osteolysis along prosthesis*

| | Normal X ray | Osteolysis along prosthesis |
|---|---|---|
| Flexion normal | 38 | 6 |
| Flexion reduced >25° | 9 | 7 |
| Abduction normal | 28 | 1 |
| Abduction reduced >20° | 19 | 12 |

*Table 7 Reduced hip mobility—Settling of prosthesis*

| | No settling (0–20 mm) | Settling more than 20 mm |
|---|---|---|
| Flexion normal | 37 | 7 |
| Flexion reduced >25° | 8 | [illegible] |
| Abduction normal | 27 | 2 |
| Abduction reduced >20° | 18 | 13 |

*Table 8 Impaired walking capacity—Quadriceps muscle insufficiency*

| | Sufficient quadriceps (strength 4–5) | Insufficient quadriceps (strength 0–3) |
|---|---|---|
| Walking more than 200 m | 20 | 9 |
| Walking less than 200 m | [illegible] | 21 |

One patient with femoral amputation was unable to walk for that reason

*Table 9 Painless hips with good mobility—Ossification in prosthetic fenestrae*

| | No visible ossification | Marked ossification |
|---|---|---|
| No pain | 9 | 33 |
| Pain | 13 | 4 |
| Flexion normal | 13 | 31 |
| Flexion reduced >25° | 10 | 6 |
| Abduction normal | [illegible] | 23 |
| Abduction reduced >20° | 17 | 14 |

Ossification Clearly visible bone formation in fenestrae
One patient was not able to give information about pain.

*Table 5 Clinical observations at follow-up of 60 patients*

| | |
|---|---|
| *Pain* | |
| No pain | 34 |
| Minimal pain (not affecting activity) | 8 |
| Moderate pain (affecting activity, analgetics regularly) | 10 |
| Severe pain (affecting activity seriously) | 7 |
| Pain preventing activity or sleep | 0 |
| No information | 1 |
| *Mobility of the hip* | |
| Flexion more than 90° / Abduction more than 25° | 25 |
| Flexion 0–90° / Abduction less than 25° | 7 |
| Flexion 0–80° | 12 |
| Flexion 0–60° | 10 |
| Flexion 0–40° | 2 |
| Clinical anchylosis (correct anatomic position) | 4 |
| Clinical anchylosis (faulty anatomic position) | 0 |
| *Walking capacity* | |
| Walking distance | |
| more than 1500 m | 14 |
| 500–1500 m | 10 |
| 200–500 m | 10 |
| 75–200 m | 12 |
| not able to walk (i e less than 75 m) | 19 |
| Walking aids | |
| unaided or one cane | 29 |
| two canes or crutches | 12 |
| few steps with human aid | 11 |
| not able to walk | 8 |

quadriceps muscle ($P < 0.001$) as shown in Table 8, while insufficiency of the gluteus medius muscle as seen in 36 patients (60 per cent) could not be related to reduced walking ability

It is noteworthy that hips free of pain show a high correlation ($P < 0.001$) to the existence of marked ossification in the prosthetic fenestres, this also significantly ($P < 0.05$) correlated to hips with a good range of motion (Table 9) We have not, however, been able to determine the conditions which make for painful hips after arthroplasty in our material

The final results of the clinical examination were classified according to the criteria adopted by the American Academy of Orthopedic

*Table 11 Reduction of vitality at follow-up of 60 patients*

| Preoperatively | | At follow up: Unreduced working capacity | Slightly reduced working capacity | Unreduced daily activity | Nursing home patient |
|---|---|---|---|---|---|
| Unreduced working capacity | 23 | 13 | 4 | 4* | 2 |
| Slightly reduced working capacity | 9 | | 2 | 6 | 1 |
| Unreduced daily activity | 22 | | | 10 | 12* |
| Nursing home patient | 6 | | | | 6 |
| Total number | [redacted] | 13 | 6 | 20 | 21 |

*Unreduced daily activity* = able to manage personal needs independently but unable to work

*Reduced vitality as shown at the right side of the crossline was found in 29 of 60 patients but was in only two cases (in groups marked *) due to the hip arthroplasty*

Roentgenological findings at long term follow up have been described by only a small number of authors (Andersson et al 1964, Andersson & Nielsen 1972 Barr et al 1964, Danielsson 1965, Polyzoides 1971, Whittaker et al 1972) Thus, settling has been noted in 17 per cent of cases by Andersson et al (1964) and in 90 per cent by Polyzoides (1971) The usual figure lies around 35 per cent (Andersson & Nielsen 1972, Barr et al 1964, Whittaker et al 1972) The degree of settling has not been stated however We found the settling to be of no importance for the mobility of the hip unless it amounted to more than 20 *mm* as found in 25 per cent of our patients

Osteolysis along the prosthetic stem was found by Andersson et al (1964) in 6 per cent of cases Andersson & Nielsen (1972) and Whittaker et al (1972) noted 32 per cent These authors have interpreted the osteolysis as a sign of looseness of the prosthesis, and the latter suggested this as a cause of pain We found osteolysis in 22 per cent of the patients but in our series it was not correlated to pain On the contrary we found ossification in the fenestres of the prosthesis to be convincingly ($P < 0.001$) related to freedom from pain

Migration was described by Whittaker et al (1972) in 24 per cent of

*Table 10. Results classified according to the American Academy of Orthopedic Surgeons*

| | | |
|---|---|---|
| Excellent | Slight or no pain<br>Mobility 75 per cent of normal<br>Walking not affected | 18 |
| Good | Minimal pain<br>Mobility 50 per cent of normal<br>Walking with one or two canes | 13 |
| Fair | Moderate pain<br>Mobility less than 50 per cent<br>Walking with human aid | 26 |
| Poor | Bound to wheel chair or bed ridden | 3 |

The criteria for the classification are listed in the table.

Surgeons (Goodwin 1968). In Table 10 we have classified the results as fair in patients disabled from unrelated diseases if the hip was painless and with a good range of movement. One result was classified as poor since the prosthesis had to be removed as a result of infection.

Apart from the classification according to pain, hip mobility and walking capacity we have analysed the material with respect to reduction of vitality for our patients during the observation period. This is determined by increasing age of the patients, by simultaneously occurring but unrelated diseases, and by fracture complications. As shown in Table 11 the vitality of 29 out of 60 patients (48.3 per cent) decreased, but only in two cases was this due to the hip arthroplasty.

## DISCUSSION

Long term results after Moore arthroplasty have generally been acceptable. Excellent and good results have generally been achieved in 60–70 per cent of cases (Hinchey & Day 1964, Jansen & Ruben Hansen 1965, Polyzoides 1971, Salvati & Wilson 1973). However, the number of poor results varies considerably and has ranged from 6 [illegible] per cent (Polyzoides 1971, Salvati & Wilson 1973) up to 22–26 per cent (Andersson & Nielsen 1972, Whittaker et al. 1972). Fifteen per cent poor results seems to be about average (Barr et al. 1964, Golden 1969, Hinchey & Day 1964, King et al. 1959, Mayer & Sarkar 1964).

The results in our series thus show good correlation with the results given in previous publications.

of 4 9 years Of these, 8 3 per cent sustained femoral fractures during this period

The results classified according to the criteria of the American Academy of Orthopedic Surgeons showed 52 per cent excellent or good, 43 per cent fair and 5 per cent poor results

The roentgenological finding of settling or osteolysis along the prosthesis was significantly correlated to reduced hip mobility Ossification in the prosthetic fenestres gave significantly diminished settling, and was correlated to better hip mobility and less pain

In our opinion, Moore arthroplasty has proved to be an acceptable method for the treatment of femoral neck fractures in elderly patients, as 73 per cent had an acceptable range of motion 40 per cent managed walking distances of more than 500 m and 70 per cent had minimal or no pain Although 25 per cent became nursing home patients, this reduction of vitality could be related to the hip arthroplasty in only two cases

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cases after 5 years Andersen & Nielsen (1972) and Polyzoides (1971) found the same frequency of migration as in our material (17 per cent) Our series does not reveal migration to be pertinent to pain or hip mobility

No detailed information concerning hip mobility at long term follow up is available We found 78 per cent of our patients to have sufficient flexion of the hip (0–80°) to be able to put on shoes Hip mobility was significantly impaired ($P < 0.05$) in cases of osteolysis along the prosthesis as well as in the case of settling On the other hand we found good hip mobility as well as reduced pain significantly ($P < 0.05$ and $P < 0.001$) correlated to marked ossification in the fenestres of the prosthesis, and we also found that ossification diminishes settling ($P < 0.001$) Thus we believe that it is very important to employ prostheses with fenestres that can be filled with bone chips

As regards walking capacity King et al (1959) indicated that 61 per cent could walk using one or no cane while 21 per cent needed two canes Harris (1966) found, however, that 65 per cent needed two canes or crutches Among our patients 48 per cent were able to walk using one or no cane, 20 per cent needed two canes or crutches, while 40 per cent were able to walk more than 500 m In our series walking ability was significantly ($P < 0.001$) reduced by insufficiency of quadriceps muscular function

In our opinion Moore arthroplasty has proved to be an acceptable method for the treatment of femoral neck fractures in elderly patients As many as 73 per cent had an acceptable range of hip motion, 40 per cent managed walking distances of more than 500 m and 70 per cent had minimal or no pain Although 15 (25 per cent) of these elderly patients became nursing home patients the decrease in vitality can be directly related to the hip arthroplasty in only two cases

## SUMMARY

Moore arthroplasty was performed for medial femoral neck fractures in 169 patients

The mortality rate was 21 3 per cent within [illegible] months The general postoperative complication rate (39 6 per cent) was dominated by cardiopulmonary (17 2 per cent) and thromboembolic (16 0 per cent) events Of local complications, wound infection was found in 4 7 per cent and osteitis in 3 0 per cent of cases

A total of 60 patients were followed up with a mean observation time

Acta orthop scand 46, 775–781, 1975

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# CLASSIFICATION OF MEDIAL FRACTURES OF THE FEMORAL NECK

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Accepted [illegible] xii 74

The first classification of femoral neck fractures was undertaken by Cooper (1823), who divided them into intracapsular and extracapsular fractures. His division was based on the various prognoses for recovery in this type of fracture. It was later observed that it was possible to distinguish different basic types of intracapsular or medial fractures. In the first classification, such fractures were called "subcapital" or "most lateral", depending on where the line of fracture ran (Kocher 1896, Faltin 1924, Anschutz & Portwich 1927). On a somewhat different basis, medial fractures of the femoral neck have also been divided according to the manner of dislocation, into abduction fractures and adduction froctures (Waldenström 1924, Cotton 1927, Böhler & Jeschke 1938). Nyström (1938) called these fractures valgus and varus fractures. Watson-Jones (1955) made an original division based upon the age of the patient and he concluded that a certain type of fracture was typical for certain age groups.

It has been observed that there are considerable prognostic differences between different types of medial fractures of the femoral neck and this has been considered to be due to the position of the fracture in the femoral neck. The steeper the angle of fracture, the worse the bone union prognosis (Lofberg 1924, Howard & Christophe 1934, Nyström 1935, Lehmann 1936, Böhler & Jeschke 1938). The best-known work on the subject is that published by Pauwels (1935), who divides medial fractures into three groups according to the angle formed between the line of fracture and the horizontal. His groups are as follows:

1) angle 0°–30°
2) angle 30°–50°
3) angle over 50°

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*Key words* Moore arthroplasty hip prosthesis femoral neck fractures arthroplasty

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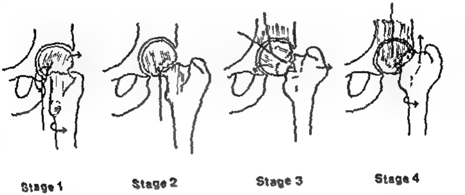



*Figure 2 Garden's classification of medial fractures of the femoral neck (After DePalma 1970)*

Studies of clinical series in which medial fractures have been divided according to the above classification have been made by Garden (1961), Brown & Abrams (1964), Graham (1968) and Barr (1973). In his manual on fractures, DePalma (1970) adopts Garden's classification.

In order to obtain a practical and coherent classification of medial fractures of the femoral neck, the present authors undertook a comparative study which fell midway between Pauwels' scheme, in which the criterion was the direction of the line of fracture and Garden's scheme in which classification was based on the degree of *primary* dislocation. The guiding criterion for comparison was the prognosis for recovery.

## MATERIALS AND METHODS

The series of patients comprised all those who were treated for medial fractures of the femoral neck between the years 1964 and 1971 in the city of Turku, Finland (The University Hospital in Turku and also the Municipal Hospital of Turku). Cases of pathological fracture were not included in the study. The study deals with 446 medial fractures of the femoral neck in a total of 436 patients. This was 56.3 per cent of all recorded cases of fracture of the proximal end of the femur. In the retrospective study medial fractures were classified according to the scheme of Garden (1961) and Pauwels (Leitz 1966) and, on the basis of the most recent X-ray photographs available, bone union and failure were classified, as well as cases where there was necrosis of the femoral head. Necrosis was considered to exist when there was late segmental collapse of the femoral head (Barnes 1962, Bohr & Larsen 1965, Catto 1965). Progress of recovery was classified on the basis of the above fracture groups.

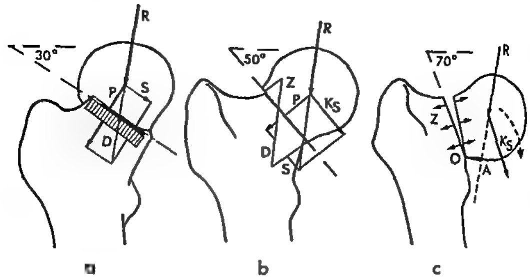


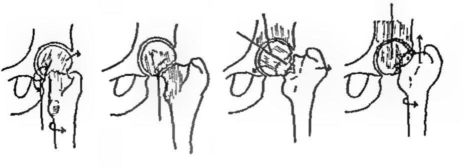

*Figure 1 Pauwels classification of medial fractures of the femoral neck*

The classification by Pauwels has also been completed by adding a so-called "fourth" group in which, on the angled line of fracture there is, in the lower part of the femoral neck a tonguelike 'basal-sporn' formation, running distally (Leitz 1966) In the Pauwels' scheme, this form is the most unstable of all

The prognostic significance of Pauwels' angle has been considered unsatisfactory (Spotoft 1944, Linton 1944, 1949, Nieminen 1974) It has also been difficult to define the angle required for classification (Garden 1961) Recently it has been thought that in the case of medial fracture it is the degree of primary dislocation that correlates with the prognosis of recovery (Linton 1949, Spotoft 1949, Backman 1957, Fielding et al 1962)

On this basis, Garden (1961) made a classification of medial fractures of the femoral neck which has been widely adopted in English and American studies of the subject On the basis of primary X-ray findings, he divided fractures as follows

Stage 1 · incomplete fracture (This group consists principally of impacted valgus fractures)
Stage 2 complete fracture without displacement
Stage 3 complete fracture with partial displacement (In this type the posterior capsule of the joint has remained intact)
Stage 4 complete fracture with full displacement



Stage 1 Stage 2 Stage 3 Stage 4

*Figure 8 Garden's classification of medial fractures of the femoral neck (After DePalma 1970)*

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*Table 1. Distribution of fracture cases according to the classifications of Garden and Pauwels*

| Garden | Pauwels 1 | 2 | 3 | 4 | Together |
|---|---|---|---|---|---|
| 1 | [illegible] (1) | 49 (11) | 14 ( 3) | 1 | [illegible] ( 16) |
| 2 | – – – | 5 ( 1) | 4 ( 1) | – – – | 9 ( 2) |
| 3 | – – – | 18 ( 4) | 21 ( 5) | 1 | 40 ( 9) |
| 4 | 7 (2) | 180 (40) | 127 (29) | 12 (3) | 326 ( 73) |
| Together | 12 (3) | 252 (57) | 166 (37) | 14 (3) | 444 (100) |

In brackets, percentage of all cases

*Table 2 Progress of healing grouped according to the distribution of fractures by Garden and Pauwels*

| Garden / Pauwels | | 1 / 1 | 2 / 2 | 3 / 3 | 4 / 4 |
|---|---|---|---|---|---|
| Bone union | per cent | 86 / 60 | 75 / 63 | 61 / 51 | 51 / 46 |
| Failed | per cent | 3 / 20 | 13 / 16 | 29 / 30 | 26 / 48 |
| LSC | per cent | 11 / 20 | 20 / 24 | 18 / 17 | 25 / 13 |

LSC = Late segmental collapse of the femoral head

## FINDINGS

Out of the 446 medial fractures considered in this study, it was possible in the case of all but two to make definitions according to the classifications of Garden and Pauwels. The distribution of fracture cases according to these classifications will be seen in Table 1.

Table 2 shows the retrospective evaluation of progress of healing in fracture cases, grouped according to the type of fracture. Necroses of the femoral head were calculated on the basis of fracture cases where there had been a follow-up of at least 1 year. Garden's division proved to be more logical than that of Pauwels. Particularly in the analysis of stable and non-dislocated fractures there was a statistically significant difference ($P < 0.01$) and in the case of failures a highly significant ($P < 0.001$) difference as far as bone union was concerned, compared to the results when Pauwels' division was analysed. It was impossible to show any statistical connection between the number of cases where there was necrosis of the femoral head and the classification of fractures used.

## DISCUSSION

In the present study cases of medial fracture were divided in a similar manner to that of previous studies (Brown & Abrami 1964 Bahr et al 1971 Massie 1973) In the studies made by Garden (1961 1971) and Graham (1968) Garden's 3rd degree fractures were considerably more common As Brown & Abrami (1964) emphasized distinguishing between the 3rd and 4th degrees is difficult and to some extent a question of interpretation and for this reason these degrees are often dealt with as a single group No clear correlation could be observed between the different classifications It may be possible to explain this lack of correlation by the fact that definitions of stability (Pauwels angle) were made from X rays on the frontal view and that the level and direction of the fracture seen on the lateral view were not taken into account As a criterion for the determination of stability the aforementioned view is just as important as the frontal view (Backman 1957) In the Pauwels classification this is however not taken into account

Evaluated on the basis of Table 2 Garden's division shows itself to be much more logical and from the point of view of both bone union and failure prognostically more reliable Spotoft (1949) and Massie (1973) have also considered the degree of primary dislocation in medial fractures a prognostically superior system of calculation to that of Pauwels In practice the Pauwels angle is difficult to measure its value is dependent upon the degree of rotation of the femur and the angle changes on account of impaction The fracture can often be classified in different groups before and after nailing (Garden 1961) and the value of the classification has been considered unsatisfactory from the point of view of prognosis of recovery (Spotoft 1944 Linton 1944 1949 Because of its simplicity and because determinations can be made without measurements and also because of its prognostic reliability for bone union Garden's division of medial fractures of the femoral neck can be recommended as the basic classification for clinical work

## SUMMARY

In this study 444 consecutive cases of medial fracture of the femoral neck treated in the city of Turku are considered on the basis of the proposals of Garden (1961) and Pauwels (Leitz 1966) for the classification of fracture types In order to find out what kind of classifica

tion is most practical and coherent a retrospective comparison of the progress of healing was made on the basis of the aforementioned classifications of fracture Garden's classification proved to be far more logical and was much more reliable for the prognosis of recovery For this reason and also because of the ease with which his criteria can be applied, the present authors recommend the general use of Garden s classification

## ACKNOWLEDGEMENTS

This study was supported by grant from the National Pensions Institute

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*Key w rds* fem ral neck fractures classification

C rresp ndence t

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tion is most practical and coherent a retrospective comparison of the progress of healing was made on the basis of the aforementioned classifications of fracture Garden's classification proved to be far more logical and was much more reliable for the prognosis of recovery For this reason and also because of the ease with which his criteria can be applied, the present authors *recommend the general use of Garden's classification*

## ACKNOWLEDGMENTS

This study was supported by grant from the National Pensions Institute

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was 3 years After this 3-year period, no difference was observed, as far as failure of fixation or pseudoarthrosis were concerned, between patients who started weightbearing early or late (late being 12 weeks after the nailing) Necroses of the femoral head were even more common among late weightbearing patients The difficulty of finding truly comparable groups for this kind of study has been stressed by Graham There are studies by Garden (1961), Bonnin & Cashman (1963), Smyth et al (1964), Hullinger (1967) and Ainsworth (1971) in which the authors show that among patients treated with low-angle nailing and who were also early weight-bearers there was no increase in necroses of the femoral head

The department of internal medicine in the Municipal Hospital in Turku has developed special facilities for the treatment of long-term patients and elderly people Because long periods in bed are especially trying for elderly patients and easily lead to mental and physical collapse, patients with hip fractures in this hospital are got onto their feet as soon as possible This policy has been followed in the hospital since 1960 In the case of medial fracture of the femoral neck patients are allowed to bear their own total weight, by degrees, within 3 weeks of operation (Ruikka 1972) The following study was made possible by the putting into practice of this policy and the object was to determine the effect of early weightbearing on the late results of treatment for medial fracture of the femoral neck after the classical nailing method

## MATERIAL AND METHODS

The study includes all adult patients treated over an 8 year period between 1964 and 1971 primarily for medial fracture of the femoral neck in the surgical clinics of the University Hospital in Turku and the Municipal Hospital in the same city In all 43[illegible] patients are considered and during the period under review there were 446 medial fractures of the femoral neck This figure is 56.3 per cent of all recorded fractures of the proximal end of the femur Male patients (average age 66.3 years) accounted for 17.5 per cent of the total and females (average age 73.9 years) 82.5 per cent The overall average age was 72.6 years and ages ranged from 16.7 to 9[illegible] years *Operations were carried out on* 413 patients (92.6 per cent) and there were no emergency nailings The majority of the fractures were fixed by means of Smith Petersen nails and side plates (49.4 per cent) or only with Smith Petersen nails (45.4 per cent) In 10 cases (2.2 *per cent*) treatment was with primary prosthetic replacement The primary mortality rate for fracture cases (within 30 days of the accident) was 12.3 per cent and the operative mortality rate was 9.4 per cent A deep vein thrombosis which gave clinical symptoms occurred in 3.2 per cent of the patients After nailing there was infection of the wound in

Acta orthop scand 46, 782–794, 1975

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# EARLY WEIGHTBEARING AFTER CLASSICAL INTERNAL FIXATION OF MEDIAL FRACTURES OF THE FEMORAL NECK

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Accepted 4.vi.75

The treatment of medial fractures of the femoral neck is still a difficult undertaking, and the various factors involved are as yet imperfectly understood. Bone union does not always take place and late complications are common (Barnes 1970). The wide use of treatment with a primary prosthetic replacement has not solved the problem (Gossling & Hardy 1969, Lunt 1971, Evarts 1973, Hunter 1974). Although it has been possible by means of internal fixation methods, based on low-angle nailing, to improve the weightbearing stability of the nailed fracture (Spotoft 1944, Kuntscher 1954, Backman 1957, Garden 1961, Bonnin & Cashman 1963) failures are common even in patients treated in this way (Ainsworth 1971, Massie 1973).

A long period without weightbearing, even up to [illegible] months, has generally formed a part of the treatment based on the classical nailing method. (The nail runs along the central axis of the femoral neck in the manner of, for example, Smith-Petersen or Johansson) (DePalma 1970, Campbell 1971). This has been considered necessary not only because of the instability of the fracture, but also because early compression is thought to increase the possibility of necrosis of the femoral head (Rokkanen & Slätis 1967). However, as long ago as 1937 Moore observed that early weightbearing after nailing did not increase the likelihood of late complications. There have been a number of comparative studies since then in which, as a sequel to the classical nailing method, some of the patients were allowed to use the limb for weightbearing rather soon (approximately 2 weeks) after the nailing of the fracture (Gibson 1964, Brown & Abrami 1964, Häggqvist 1969). However, the follow-up period in these studies has never been longer than 1 year. In a similar study by Graham (1968) the follow-up period

was 3 years After this 3 year period, no difference was observed, as far as failure of fixation or pseudoarthrosis were concerned, between patients who started weightbearing early or late (late being 12 weeks after the nailing) Necroses of the femoral head were even more common among late weightbearing patients The difficulty of finding truly comparable groups for this kind of study has been stressed by Graham There are studies by Garden (1961), Bonnin & Cashman (1963), Smyth et al (1964), Hullinger (1967) and Ainsworth (1971) in which the authors show that among patients treated with low-angle nailing and who were also early weight-bearers there was no increase in necroses of the femoral head

The department of internal medicine in the Municipal Hospital in Turku has developed special facilities for the treatment of long-term patients and elderly people Because long periods in bed are especially trying for elderly patients and easily lead to mental and physical collapse, patients with hip fractures in this hospital are got onto their feet as soon as possible This policy has been followed in the hospital since 1960 In the case of medial fracture of the femoral neck patients are allowed to bear their own total weight, by degrees, within 3 weeks of operation (Ruikka 1972) The following study was made possible by the putting into practice of this policy and the object was to determine the effect of early weightbearing on the late results of treatment for medial fracture of the femoral neck after the classical nailing method

## MATERIAL AND METHODS

The study includes all adult patients treated over an 8 year period between 1964 and 1971 primarily for medial fracture of the femoral neck in the surgical clinics of the University Hospital in Turku and the Municipal Hospital in the same city In all 436 patients are considered and during the period under review there were 446 medial fractures of the femoral neck This figure is 56 3 per cent of all recorded fractures of the proximal end of the femur Male patients (average age 66 3 years) accounted for 17 5 per cent of the total and females (average age 73 9 years) 82 5 per cent The overall average age was 72 6 years and ages ranged from 16 7 to 9 7 years Operations were carried out on 413 patients (92 6 per cent) and there were 11 emergency nailings The majority of the fractures were fixed by means of Smith Petersen nails and side plates (49 4 per cent) or only with Smith Petersen nails (43 4 per cent In 10 cases (2 2 per cent) treatment was with primary prosthetic replacement The primary mortality rate for fracture cases (within 30 days of the accident) was 12.3 per cent and the operative mortality rate was 9 4 per cent A deep vein thrombosis which gave clinical symptoms occurred in 3 3 per cent of the patients After nailing there was infection of the wound in

16 cases (4.0 per cent) and of these, 12 (3.0 per cent) had a superficial infection and four (1.0 per cent) a deep infection (cf. Nieminen 1974).

### *Post-operative treatment*

Cases of fracture in the geographical area served by the University Hospital (representing a population of approximately 250 000) were first treated surgically either in the surgical clinic of the University Hospital or in the department of surgery of the Municipal Hospital. If beds were available, patients with fractures who were officially resident in Turku were treated post-operatively in the department of internal medicine in the Municipal Hospital. Weightbearing was allowed for these patients at an early phase, 2 weeks after nailing. Post-operative treatment of patients resident elsewhere was carried out in local institutions or at home and in these cases weightbearing after medial fracture of the femoral neck was not allowed until 12–24 weeks after nailing. Whether a patient bore weight early (i.e. in the Municipal Hospital) or late was therefore residence dependent and in this sense haphazard.

### *Results of treatment*

In the retrospective evaluation of the results of treatment, patients were divided as above into two groups—early weightbearing patients (EW, 2 weeks after operation) and late weightbearing patients (LW, 12–24 weeks after operation). Fractures were grouped both according to primary dislocation (Garden 1961) and according to the classical division of Pauwels (1935). The Pauwels division was completed by the addition of a fourth group (Leitz 1966). Those patients who were still alive and were adjudged, on the basis of an X-ray, to have had an insufficient follow-up (minimum period 2 years) were asked to come for a further examination. Bone union failure (pseudo-arthrosis) and necrosis of the femoral head were defined on the basis of the ultimate X-ray in order to clarify results. Necrosis of the femoral head was defined on the basis of late segmental collapse of the femoral head (Barnes 1962, Bohr & Larsen 1965a, Catto 1965 b).

## RESULTS

Excluded from the groups of early (EW) and late (LW) weightbearing patients were those who died post-operatively or, on account of an accident, within 30 days. Table 1 shows the age distribution of patients and the number of fractures. There was no significant difference ($P > 0.05$) between the age distribution of the two groups. There were 63 EW cases (52.5 per cent) who were followed up for at least 2 years, the average period being 4.7 years (2.1–9.4). There were 80 LW cases (30.6 per cent) similarly followed up, the average period being 4.2 years (2.0–9.9).

Primary classification of fractures according to patient group is shown in Table 2. Dislocated fractures were almost significantly

*Table 1 Average age of patient groups and number of fracture cases*

| | Average age in years | Fracture cases |
|---|---|---|
| Early weightbearing patients (26 9 per cent of all fracture cases in the study) | | |
| Men | 65 1 ± 14 6 | 19 (15 8 %) |
| Women | 71 8 ± 10 5 | 101 (84 2 %) |
| All patients | 70 7 ± 11 4 | 120 (100 0 %) |
| Late weightbearing patients (58 5 per cent of all fracture cases in the study) | | |
| Men | 64 9 ± 13 5 | 50 (19 2 %) |
| Women | 73.3 ± 9.8 | 211 (80 8 %) |
| All patients | 71 7 ± 11 0 | 261 (100 0 %) |

*Table 2 Distribution of fracture types according to patient groups*

| Classification | | EW per cent | LW per cent |
|---|---|---|---|
| Garden | 1 | 23 4 | 13 0 |
| | 2 | 2 5 | 1 5 |
| | 3 | 5 8 | 9 2 |
| | 4 | 68.3 | 75 5 |
| Pauwels | 1 | 3 3 | 2.3 |
| | 2 | 69 2 | 53 3 |
| | 3 | 24 3 | 40 2 |
| | 4 | 3 5 | 3 4 |

EW = early weightbearing patients, LW = late weightbearing patients

($P < 0\ 05$) more numerous in the LW-group (Garden's 3rd–4th stage) and unstable fractures (Pauwel's 3–4) were significantly ($P < 0\ 01$) more numerous than in the EW-group It will be seen, however, from Tables 3 and 4 that EW-patients showed better recovery than LW-patients irrespective of the type of fracture Statistically, the greatest differences are to be seen in the largest groups Among EW-patients, Garden's 4th degree fractures, in which bone union took place, were significantly ($P < 0\ 01$) more numerous than among LW-patients and similarly there were significantly more ($P < 0\ 01$) cases of bone union among EW-patients in the two groups of Pauwels' fractures than among LW-patients If we consider the type of nailing used, fractures

*Table 3 Progress of healing in early weightbearing patients in relation to various factors*

| | Garden | | | | Pauwels | | | | Type of nail | | Others |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | S–P | S P + side plate | |
| Follow up 2 years | | | | | | | | | | | |
| Cases | 19 | 1 | 3 | 40 | 1 | 46 | 12 | 4 | 14 | 43 | 2 |
| Bone union | 19 | 1 | 2 | 37 | 1 | 43 | 12 | 4 | 13 | 40 | 2 |
| Failed | | | 1 | 3 | – | 3 | – | 1 | 1 | 3 | – |
| LSC | 2 | | 1 | 12 | – | 14 | 1 | – | 4 | 10 | 1 |
| Total | | | | | | | | | | | |
| Cases | 28 | 3 | 7 | 82 | 4 | 83 | 29 | 4 | 23 | 87 | 4 |
| No follow up | 2 | | 1 | 13 | 1 | 9 | 6 | – | 3 | 12 | 2 |
| Bone union | 25 | 3 | 4 | 53 | 3 | 63 | 16 | 3 | 15 | 62 | 1 |
| Failed | 1 | | 2 | 16 | – | 11 | 7 | 1 | 5 | 13 | 1 |
| LSC | 2 | | 1 | 13 | – | 15 | 1 | – | 5 | 10 | 1 |

S P = Smith Petersen LSC = Late segmental collapse of the femoral head

*Table 4 Progress of healing in late weightbearing patients in relation to various factors*

| | Garden | | | | Pauwels | | | | Type of nail | | Others |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | S-P | S P + side plate | |
| F U = up 2 years | | | | | | | | | | | |
| Cases | 17 | [illegible] | 9 | 51 | 3 | 39 | 36 | 2 | 42 | [illegible] | 6 |
| Bone union | 16 | [illegible] | 7 | [illegible] | [illegible] | 38 | 24 | 1 | 34 | 22 | 5 |
| Failed | 1 | 1 | 2 | 11 | 1 | 1 | 12 | 1 | 8 | 6 | 1 |
| LSC | 1 | 1 | 2 | 10 | 1 | 10 | 8 | 1 | 9 | 8 | 2 |
| Total | | | | | | | | | | | |
| Cases | 34 | 5 | 24 | 197 | 6 | 130 | 105 | 9 | 141 | 92 | 16 |
| No follow up | 5 | 1 | 1 | 48 | 1 | 36 | 17 | – | 33 | 16 | 3 |
| Bone union | 29 | 3 | 15 | 88 | 3 | 76 | 52 | 3 | 75 | 42 | 9 |
| Failed | 1 | 1 | 8 | 61 | [illegible] | 27 | 36 | 6 | 33 | 34 | 4 |
| LSC | 2 | 1 | 2 | 23 | 1 | 13 | 13 | 1 | 14 | 11 | 2 |

S P = Smith Petersen LSC = Late segmental collapse of the femoral head

*Table 3 Progress of healing in early weightbearing patients in relation to various factors*

| | Garden | | | | Pauwels | | | | Type of nail | | Others |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | S–P | S–P + side plate | |
| Follow up 2 years | | | | | | | | | | | |
| Cases | 19 | 1 | 3 | 40 | 1 | 46 | 12 | 4 | 14 | 43 | 2 |
| Bone union | 19 | 1 | [illegible] | 37 | 1 | 43 | 12 | 4 | 13 | 40 | 2 |
| Failed | | | 1 | 3 | – | 3 | – | 1 | 1 | 3 | – |
| LSC | 2 | – | 1 | 12 | – | 14 | 1 | – | 4 | 10 | 1 |
| Total | | | | | | | | | | | |
| Cases | 29 | 3 | 7 | 82 | 4 | 83 | 29 | 4 | 23 | 87 | 4 |
| No follow up | 2 | – | 1 | 13 | 1 | 9 | 6 | – | [illegible] | 12 | 2 |
| Bone union | 25 | 3 | 4 | 53 | 3 | 63 | 16 | 3 | 15 | 62 | 1 |
| Failed | 1 | – | [illegible] | 16 | – | 11 | 7 | 1 | 5 | 13 | 1 |
| LSC | 2 | – | 1 | 13 | – | 15 | 1 | – | 5 | 10 | 1 |

S–P = Smith Petersen LSC = Late segmental collapse of the femoral head

*Table 7. Perforations of the surface of the femoral head caused indirectly by the nail*

| | Nail with side plate | Nail without side-plate | |
|---|---|---|---|
| EW | 21 1 per cent | 12 5 per cent | $P > 0\ 05$ |
| LW | 33 3 per cent | 10 7 per cent | $P < 0\ 001$ |
| | $P < 0\ 05$ | $P > 0\ 05$ | |

EW = early weightbearing patients, LW = late weightbearing patients

*Table 8 Progress of healing in patient groups according to time-lag between accident and nailing*

| Date of nailing | Cases | No follow-up (per cent) | Bone union (per cent) | Failed (per cent) | LSC (per cent) |
|---|---|---|---|---|---|
| 1–3 days | | | | | |
| EW | 30 | 16 7 | 66 7 | 16 7 | 13 3 |
| LW | 76 | 23 7 | 46 1 | 30 3 | 13 2 |
| | | $P > 0\ 05$ | $P < 0\ 05$ | $P > 0\ 05$ | $P > 0\ 05$ |
| 4 7 days | | | | | |
| EW | 62 | 14 5 | 69 4 | 16.1 | 14 5 |
| LW | 129 | 22 5 | 55 8 | 21 7 | 10 1 |
| | | $P > 0\ 05$ | $P > 0\ 05$ | $P > 0\ 05$ | $P > 0\ 05$ |
| > 7 days | | | | | |
| EW | 22 | 18 2 | 72 8 | 9 1 | 13 6 |
| LW | 44 | 22 7 | 41 0 | 36 4 | 9 1 |
| | | $P > 0\ 05$ | $P < 0\ 05$ | $P < 0\ 05$ | $P > 0\ 05$ |

EW early weightbearing patients, LW = late weightbearing patients
LSC Late segmental collapse of the femoral head

cases which were followed up for more than 2 years necroses of the femoral head were even relatively more common among LW-patients than among EW-patients

There was no relative difference between the two groups as far as the number of complications arising from nailing were concerned (Table 6) Few symptoms generally resulted from the perforation of the surface of the femoral head caused by nailing This type of complication (Table 7) was not aggravated by early weightbearing on the fractured limb, even in cases where a side-plate was used

The time-lag between the accident and the nailing had no significant effect on the healing of the fracture, although in the EW-group in those cases where the fracture was nailed more than 7 days after the

*Table 5 Progress of healing in the whole study according to patient groups*

| | | Cases | No follow up (per cent) | Bone union (per cent) | Failed (per cent) | LSC (per cent) |
|---|---|---|---|---|---|---|
| Follow-up 2 years | | | | | | |
| | EW | 63 | – | 59 (93 6) | 4 ( 6 3) | 15 (23 8) |
| | LW | 80 | – | 65 (81 3) | 15 (18 7) | 20 (25 0) |
| Total | | | | | | |
| | EW | 120 | 16 (13 3) | 85 (70 8) | 19 (15 8) | 16 (13 3) |
| | LW | 261 | 55 (21 1) | 134 (51 4) | 71 (27 2) | 28 (10 7) |
| | | | $P < 0\ 05$ | $P < 0\ 01$ | $P < 0\ 01$ | $P > 0\ 05$ |
| Together | | 381 | 71 (18 6) | 219 (57 5) | 90 (23 6) | 44 (11 5) |

LSC = late segmental collapse of the femoral head
EW = early weightbearing patients, LW = late weightbearing patients

*Table 6 Late complications caused by the nail*

| | EW (per cent) | LW (per cent) |
|---|---|---|
| Penetration by the nail of the surface of the femoral head | 22 (19 0) | 49 (19 7) |
| Sliding outwards of the nail | 7 (29 2) * | 30 (20 0) * |
| Collapse of the junction between nail and side plate | 8 ( 8 9) † | 7 ( 7 1) † |
| Breaking of screws in side plate | 6 ( 6 7) † | 6 ( 6 1) † |
| Breaking of side-plate | 1 | – |
| Breaking of nail | – | 1 |

EW = early weightbearing patients LW = late weightbearing patients
* (per cent) Calculated from nailings without side plate
† (per cent) Calculated from nailings with side plate

treated with Smith-Petersen nails and side-plates failed very significantly ($P < 0\ 001$) more often among LW-patients than among those who were early weightbearers

Fractures among LW patients joined better (70 8 per cent) than those among LW-patients (51 4 per cent) and there were more failures among the latter group (27 2 per cent) than with EW-patients (15 8 per cent) (Table 5)

The differences were statistically significant but there were almost significantly more cases of LW-patients who had had insufficient follow-up than EW-cases No difference could be observed between the two groups as far as necroses of the femoral head were concerned In

*Table 7 Perforations of the surface of the femoral head caused indirectly by the nail*

| | Nail with side-plate | Nail without side plate | |
|---|---|---|---|
| EW | 21.1 per cent | 12.5 per cent | $P > 0.05$ |
| LW | 33.3 per cent | 10.7 per cent | $P < 0.001$ |
| | $P < 0.05$ | $P > 0.05$ | |

EW = early weightbearing patients LW = late weightbearing patients

*Table 8 Progress of healing in patient groups according to time lag between accident and nailing*

| Date of nailing | Cases | No follow up (per cent) | Bone union (per cent) | Failed (per cent) | LSC (per cent) |
|---|---|---|---|---|---|
| 1–3 days | | | | | |
| EW | 30 | 16.7 | 66.7 | 16.7 | 13.3 |
| LW | 76 | 23.7 | 46.1 | 30.3 | 13.2 |
| | | $P > 0.05$ | $P < 0.05$ | $P > 0.05$ | $P > 0.05$ |
| 4–7 days | | | | | |
| EW | 62 | 14.5 | 69.4 | 16.1 | 14.5 |
| LW | 129 | 22.5 | 55.8 | 21.7 | 10.1 |
| | | $P > 0.05$ | $P > 0.05$ | $P > 0.05$ | $P > 0.05$ |
| > 7 days | | | | | |
| EW | 22 | 18.2 | 72.8 | 9.1 | 13.6 |
| LW | 44 | 29.7 | 41.0 | 36.4 | 9.1 |
| | | $P > 0.05$ | $P < 0.05$ | $P < 0.05$ | $P > 0.05$ |

EW early weightbearing patients LW late weightbearing patients
LSC late segmental collapse of the femoral head

cases which were followed up for more than 2 years necroses of the femoral head were even relatively more common among LW patients than among EW patients

There was no relative difference between the two groups as far as the number of complications arising from nailing were concerned (Table 6) Few symptoms generally resulted from the perforation of the surface of the femoral head caused by nailing This type of complication (Table 7) was not aggravated by early we [illegible]

[illegible] rated more than 7 days after the

*Table 5 Progress of healing in the whole study, according to patient groups*

| | | Cases | No follow up (per cent) | Bone union (per cent) | Failed (per cent) | LSC (per cent) |
|---|---|---|---|---|---|---|
| Follow-up 2 years | | | | | | |
| | EW | 63 | – | 59 (93 6) | 4 ( 6 3) | 15 (23 8) |
| | LW | 80 | – | 65 (81 3) | 15 (18 7) | 20 (25 0) |
| Total | | | | | | |
| | EW | 120 | 16 (13 3) | 85 (70 8) | 19 (15 8) | 16 (13 3) |
| | LW | 261 | 55 (21 1) | 134 (51 4) | 71 (27 2) | 28 (10 7) |
| | | | $P < 0\ 05$ | $P < 0\ 01$ | $P < 0\ 01$ | $P > 0\ 05$ |
| Together | | 381 | 71 (18 6) | 219 (57 5) | 90 (23 6) | 44 (11 5) |

LSC = late segmental collapse of the femoral head
EW = early weightbearing patients, LW = late weightbearing patients

*Table 6 Late complications caused by the nail*

| | EW (per cent) | LW (per cent) |
|---|---|---|
| Penetration by the nail of the surface of the femoral head | 22 (19 0) | 49 (19 7) |
| Sliding outwards of the nail | 7 (29 2) * | 30 (20 0) * |
| Collapse of the junction between nail and side-plate | 8 ( 8 9) † | 7 ( 7 1) † |
| Breaking of screws in side-plate | 6 ( 6 7) † | 6 ( 6 1) † |
| Breaking of side plate | 1 | – |
| Breaking of nail | – | 1 |

EW = early weightbearing patients, LW = late weightbearing patients
* (per cent) Calculated from nailings without side plate
† (per cent) Calculated from nailings with side plate

treated with Smith Petersen nails and side plates failed very significantly ($P < 0\ 001$) more often among LW-patients than among those who were early weightbearers

Fractures among EW patients joined better (70 8 per cent) than those among LW-patients (51 4 per cent) and there were more failures among the latter group (27 2 per cent) than with EW-patients (15 8 per cent) (Table 5)

The differences were statistically significant but there were almost significantly more cases of LW-patients who had had insufficient follow-up than EW-cases No difference could be observed between the two groups as far as necroses of the femoral head were concerned In

*Table 7 Perforations of the surface of the femoral head caused indirectly by the nail*

| | Nail with side-plate | Nail without side plate | |
|---|---|---|---|
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| LW | 33.3 per cent | 10.7 per cent | $P < 0.001$ |
| | $P < 0.05$ | $P > 0.05$ | |

EW = early weightbearing patients LW = late weightbearing patients

*Table 8 Progress of healing in patient groups according to time lag between accident and nailing*

| Date of nailing | Cases | No follow up (per cent) | Bone union (per cent) | Failed (per cent) | LSC (per cent) |
|---|---|---|---|---|---|
| 1–3 days | | | | | |
| EW | 30 | 16.7 | 66.7 | 10.7 | 13.3 |
| LW | 76 | 23.7 | 46.1 | 30.3 | 13.2 |
| | | $P > 0.05$ | $P < 0.05$ | $P > 0.05$ | $P > 0.05$ |
| 4–7 days | | | | | |
| EW | 62 | 14.5 | 69.4 | 16.1 | 14.5 |
| LW | 129 | 22.5 | 55.8 | 21.7 | 10.1 |
| | | $P > 0.05$ | $P > 0.05$ | $P > 0.05$ | $P > 0.05$ |
| > 7 days | | | | | |
| EW | 22 | 18.2 | 72.8 | 9.1 | 13.6 |
| LW | 44 | 22.7 | 41.0 | 36.4 | 9.1 |
| | | $P > 0.05$ | $P < 0.05$ | $P < 0.05$ | $P > 0.05$ |

EW early weightbearing patients LW — late weightbearing patients
LSC — Late segmental collapse of the femoral head

cases which were followed up for more than 2 years necroses of the femoral head were even relatively more common among LW-patients than among EW patients

There was no relative difference between the two groups as far as the number of complications arising from nailing were concerned (Table 6) Few symptoms generally resulted from the perforation of the surface of the femoral head caused by nailing This type of complication (Table 7) was not aggravated by early w... but f...

... although in the EW-group in those cases where the fracture was nailed more than 7 days after the

accident, the joining was achieved relatively more rapidly than in cases where the nailing had been more prompt. In cases where the nailing had taken place between 1 and 3 or between 4 and 7 days after the accident, the healing of the fracture followed a similar pattern in both groups. In fractures that were not nailed until more than a week after the accident bone union occurred almost significantly more frequently and failed almost significantly less frequently among EW-patients than among LW-patients.

## DISCUSSION

Early weightbearing on the injured limb after a medial fracture of the femoral neck has been considered justified because in many cases necrosis of the femoral head develops regardless of the fact that the patients have rested the limb. Furthermore, it is, in practice, often impossible to teach an elderly person to move around without putting weight on the injured limb and in any case patients often start using it on their own initiative without reference to the surgeon's instructions, and there has been no observable increase in the number of necroses of the femoral head. Sometimes there has been failure to diagnose subcapital fractures because patients have failed to consult their doctor and gone on bearing weight on the limb. Such impacted fractures usually heal excellently (Ainsworth 1971). Early weightbearing on the fractured limb has usually been in combination with low-angle nailing (Garden 1961, Smyth et al. 1964, Hullinger 1967, Ainsworth 1971). Fixation of a medial fracture by means of the classical nailing method (especially without side-plates) is technically a great deal easier than low-angle nailing. In the patients in this study nailings of medial fractures of the femoral neck were carried out in the classical manner, the nail being placed along the central axis of the femoral neck.

In addition to walking exercises, early weightbearing patients were given general therapy, which was lacking in the case of the late weightbearing patients. The latter, being either at home or in an old people's home or in a local hospital, were unable to benefit from the services of a physiotherapist. It is difficult to estimate the real effect of general therapy on recovery in the case of medial fractures. On the other hand, merely the compression on the fracture caused by weightbearing can create the most beneficial conditions possible for bone union in the case of medial fractures of the femoral neck, principally in the can

cellous bone, and also for the revascularization of the femoral head Revascularization of the femoral head takes place mainly by way of the femoral neck (Catto 1965 a) Resorption of the bone, which occurs if the osteosynthesis is not completely stable (Perren et al 1969), does not take place during compression on the fracture surfaces, but pressure heals and considerably accelerates union of the cancellous bone (Charnley & Baker 1952) It is clear that impaction caused by compression also stabilizes the fracture considerably (cf Pauwels' results for fracture groups 3 and 4, Tables 3 and 4)

In the present study the results of treatment were considered in relation to particular variables and mainly on the basis of X-ray examinations Because of the practical aims of the study this manner of proceeding may be regarded as well founded and in keeping with modern therapeutic methods Moreover, in the case of medial fractures of the femoral neck, X ray findings may be considered directly comparable to clinical results (Öhman et al 1969) In the two groups of patients studied by Garden and Pauwels, fractures healed better among the early weightbearers than among the late weightbearers The clearest differences were observed in Garden's 4th degree fractures, where bone union was achieved in 65 per cent of the EW-patients and failure was recorded in 18 per cent The corresponding figures for late weightbearers were 45 per cent ($P < 0.01$) and 29 per cent, respectively Although a relatively greater proportion of EW-cases than LW-cases were nailed with side plates, the actual number of fractures fixed by this method was approximately the same in both patient groups The results of treatment were considerably better, in the case of such fractures in the LW group than in the EW group Also in the case of patients whose fractures were nailed without a side-plate the proportion in which bone union was achieved was greater in the EW-group than in the LW group Thus the type of nailing used had no effect on the results

On the basis of clinical examination, early weightbearing on the limb after medial fracture of the femoral neck has been recommended by Moore (1937) Garden (1961), Bonnin & Cashman (1963), Smyth et al (1964) Gibson (1964), Abrami & Stevens (1964), Hullinger (1967), Schiestel (1968), Graham (1968), Häggqvist (1969) and Ainsworth (1971) On the basis of the present study, early weightbearing plus nailing can be recommended as an appropriate treatment in the case of medial fractures of the femoral neck Fixing a medial fracture by means of the classical nailing method is no great strain even for elderly

patients and should always be undertaken as the primary treatment, even in the case of a dislocated fracture No significant differences could be *observed in the results of treatment between fractures where the* nailing was performed 1–3 days or 4–7 days after the fracture or even more than a week after the accident In the case of *fractures* that were nailed more than a week after the accident, bone union was almost significantly more frequent and failure was almost significantly less frequent in EW-patients than in LW-patients This can be interpreted to mean that the compression caused by weightbearing helps bone union in medial fractures of the femoral neck In these cases, where there was a long period without reduction, it may be supposed that the extent of possible primary damage to the blood circulation and con nective tissue was similar in all cases No differences can be observed in the progress of healing between emergency operations for medial fractures of the femoral neck and those where nailing takes place later (Graham 1968) There thus seems no reason to perform emergency operations in the case of such fractures, but the first duty is to determine carefully the general state of health of the patient Early *post-operative mobility accompanied by weightbearing in the injured* limb are an aid to recovery, help the patient to achieve autonomous movement more quickly and thus reduce the length of time the patient must remain in expensive hospitalization

## SUMMARY


This study is a survey of a series of *446 patients, treated in the city* of Turku, Finland, between 1964 and 1971, for medial fractures of the femoral neck Fractures were treated by means of the classical nailing *method (nail placed along the central axis of the femoral neck, ad modum* Smith-Petersen) An unselected group of patients were treated in such a way that they were already allowed to bear weight on the injured limb 2 weeks post operatively (120 patients) The remaining patients were *not allowed to bear weight on the injured* limb until 12–14 weeks after nailing (261 patients)

The progress of recovery was studied retrospectively, a comparison being made between the early and late weightbearers Without reference to the type of fracture (according to the classifications of Garden or Pauwels) or to the method of fixing (*Smith-Petersen nail*, with or without side plate) bone union was relatively more frequent and failures were relatively less frequent among early weightbearers than

among late weightbearers. Early weightbearing had a beneficial effect upon the healing of the fracture and there was no evidence in the case of early weightbearers of any additional complications

A comparative study of the whole patient group on the basis of the time-lag between the accident and the operation—some were nailed 1–3 days, some 4–7 days and some more than a week after the fracture had taken place—revealed no significant differences

## ACKNOWLEDGMENTS

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Acta orthop scand, 46 795–803, 1975

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# TROCHANTERIC FEMORAL FRACTURES TREATED WITH McLAUGHLIN OSTEOSYNTHESIS

J STEEN JENSEN & M MICHAELSEN

Accepted 10 v 75

During the late 1940's several types of osteosynthesis materials were introduced for the treatment of trochanteric femoral fractures One type has a firm connection between nail and plate (Moore, Jewett, Neufeld) and another type, the McLaughlin apparatus, has nail and plate to be connected at varying angles by means of a nut or a bolt A Danish paper on the use of the McLaughlin apparatus was published as early as 1947 (Svend Hansen)

It soon became evident that fixation of those fractures needing medial support across the calcar femorale was problematic This led E Merwyn Evans (1949) to classify trochanteric fractures as stable or unstable During the following two decades a large number of modifications of osteosynthesis materials appeared (Boyd & Andersson 1961, Holt 1963, Clawson 1964, Mulholland & Gunn 1972). By making the osteosynthesis material sufficiently strong, it was thought that varus dislocation of the fracture could be counteracted

Partly because of this tendency and partly because of material failures, some authors (Clawson 1957, Arlt et al 1973) still prefer conservative management with extension

os

1[illegible] [illegible] 1969, Roberts et al 1972, Weigert et al 1972) Results of these displacement osteotomies have been favourable

Due to this debate we have made a retrospective analysis of the results of osteosynthesis with the McLaughlin apparatus in stable as well as unstable trochanteric femoral fractures

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*Key words* femoral neck fractures fracture fixation internal exertion

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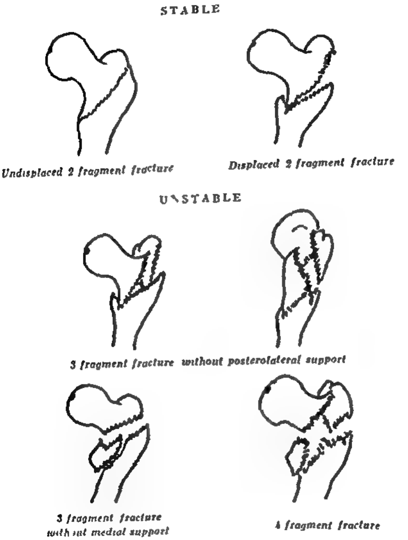


*Figure 2 Classification of trochanteric fractures according to Evans*

## RESULTS

The mortality within 3 months was 14.5 per cent. Of the 12 conservatively managed patients seven died while of the 305 operated patients 39 died (12.8 per cent). At the time of fracture, 110 patients already were nursing home patients and among the 207 patients previously capable of caring for themselves, 36 (17.4 per cent) became

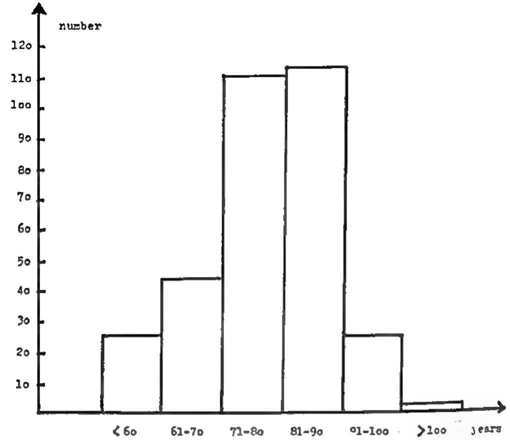


*Figure 1. Age distribution of 317 patients with trochanteric femoral fractures. Age limits: 13 to 103 years. Women: 238 patients (75.1 per cent). More than 70 years of age: 248 patients (78.2 per cent).*

## MATERIALS AND METHODS

A total of 317 patients with trochanteric fractures were treated in our department between 1967 and 1972. The age distribution is given in Figure 1. Seventy-five per cent of the patients were females. The material included one patient with spontaneous fracture; the remainder were caused by relevant trauma. Fifteen patients were on steroids (4.7 per cent) and 10 were alcoholics (3.2 per cent). Six patients (1.9 per cent) had a history of previous fracture of the same hip (one femoral neck fracture, five conservatively treated trochanteric fractures).

Of the 317 patients, 12 were treated conservatively, whereas 305 were treated with osteosynthesis with the McLaughlin apparatus. The implant used in our series consisted of a trifin vitallium nail which was connected by a topbolt to a flat vitallium blade plate of varying length. In 90 per cent of the cases a 5-hole plate was used, while a 7-, 9- or 12-hole plate was used in the other 10 per cent.

Of the 305 operated patients, 257 were followed until death or until the fracture had healed.

According to the Evans classification (1949) we subdivided the fractures into the five types shown in Figure 2.

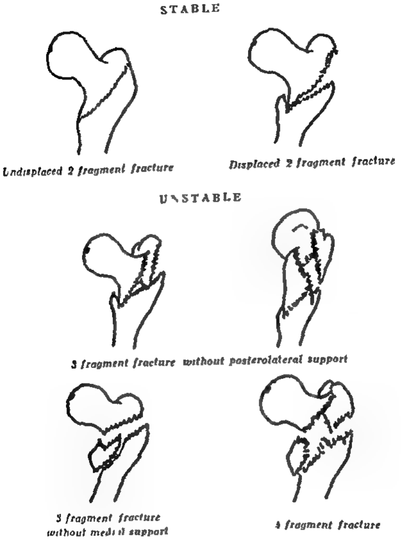


*Figure [illegible]. Classification of trochanteric fractures according to Evans*

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nursing-home patients Of the 317 patients in our series, 113 sustained general complications (Table 1) Prophylactic anticoagulant therapy was not employed This might in part explain the large number of thromboembolic events Since the material was subdivided into stable and unstable trochanteric fractures according to Evans classification (1949), these two main groups will be treated separately

*Table 1 General complications in 113 of 317 patients (35 6 per cent)*

| | |
|---|---|
| Haematoma, requiring evacuation | 5 |
| Superficial infection | 4 |
| Deep infection | 8 |
| Osteitis | 3 |
| Heart diseases | 13 |
| Pneumonia/atelectasis | 27 |
| Phlebothrombosis | 29 |
| Pulmonary embolism | 11 |
| Cerebral diseases | 5 |
| Decubitus ulcer | 14 |
| Peroneal paralysis | 3 |
| Others | 12 |

### *Stable trochanteric fractures*

The material included 106 (33 4 per cent) stable fractures, 40 were undisplaced two-fragment fractures, and 66 were displaced two fragment fractures Nine of these were treated conservatively and, of these, four patients died Ninety-seven patients underwent osteosynthesis We considered the results of this procedure ideal in 81 5 per cent of the cases Our criteria for ideal osteosynthesis are those of Sarmiento (1963) and are shown in Table 2

*Table 2 Criteria for ideal osteosynthesis according to Sarmiento*

1 Exact reposition
2 Steep placement of nail
3 Nail to parallel calcar femorale
4 Nail placed anteroposteriorly through the femoral neck
5 Nail placed slightly posteriorly in femoral head with firm hold
6 Nail 10 to 15 mm from cartilaginous border
7 Plate placed slightly anteriorly along femoral shaft

Of the 97 operated patients, 12 died during the initial hospitalization and one patient was lost to follow up, leaving 84 patients available for follow-up Of these 84 patients, 70 (83 3 per cent) were allowed weight-

bearing on the leg after 6 weeks, whereas in the remainder, weight-bearing was allowed after 8 weeks Seventy-three (86 9 per cent) of the fractures healed in an unchanged position, while fracture complications were found in 11 cases In seven patients, varus dislocation of less than 10 degrees was apparent and this displacement was of no clinical significance The remaining four had to be re-operated In two the nail had to be replaced with a shorter one because it had penetrated the articular surface of the femoral head In two patients the topbolt had to be tightened because loosening had caused varus dislocation of the fracture Thus the frequency of clinically significant fracture complications was 4 8 per cent (four of 84 patients followed up)

*Unstable trochanteric fractures*

This category included 211 fractures (66 6 per cent) 44 three-fragment fractures without posterolateral support and 73 without medial support The remaining 94 fractures had four fragments Three patients were managed conservatively and they all died in hospital Osteosynthesis was performed in 208 patients In 68 0 per cent this was ideal Among 208 operated patients, 27 died during the initial hospitalization Seven died during the control period, four were senile nursing-home patients who were not followed up Four patients were lost to follow up Thus 166 patients were followed up until the fracture had healed, but an additional three patients are included in the follow-up group since they showed fracture complications before their death during the control period

*Table 3 Fracture complications of unstable fractures in 62 of 169 patients followed up (36 7 per cent)*

| | |
|---|---|
| Migration of the nail | 14 |
| Penetration of the nail | 8 |
| Bending of the nail | 11 |
| Varus dislocation (loose topbolt) | 40 |
| Cutting of the nail | 2 |
| Loosening/breakage of the plate | 6 |
| Varus dislocation after removal of osteosynthesis material | 2 |
| Pseudarthrosis | 3 |
| Necrosis of the femoral head | 0 |

Weightbearing was allowed in 101 patients (59 8 per cent) after 6 weeks, and after 8 weeks in the others A total of 107 (67 3 per cent) of

nursing-home patients. Of the 317 patients in our series, 113 sustained general complications (Table 1). Prophylactic anticoagulant therapy was not employed. This might in part explain the large number of thromboembolic events. Since the material was subdivided into stable and unstable trochanteric fractures according to Evans classification (1949), these two main groups will be treated separately

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ment osteotomy The third patient refused operation as she was confined to a wheel-chair

Thus in 25 patients (14 8 per cent), 33 fracture complications of clinical significance were seen In 10 patients (5 9 per cent) the fracture complication led to re-operation A total of 15 re operations were performed

## DISCUSSION

Conservative management of trochanteric femoral fractures, including prolonged bedrest for this usually old and debilitated group of patients, led to a mortality rate amounting to 40 per cent (Clawson 1957, Arlt et al 1973)

Since operative treatment was introduced in the late 1940's, the mortality rate has decreased significantly In large materials it is about 13 15 per cent (Foster 1958, Holt 1963, Mulholland & Gunn 1972, Sarmiento 1963, Öhman et al 1968) This corresponds well with the overall mortality rate of 14 5 per cent seen in our series and to the rate of 12 8 per cent among only the operated patients

Among the published papers on osteosynthesis of trochanteric femoral fractures, only a few have followed the Evans classification (Clawson 1964, Cram 1955, Dimon & Hughston 1967, Foster 1958) Employing the McLaughlin apparatus as well as appliances with a firm connection between nail and plate (such as Jewett) the results of osteosynthesis of the stable fractures have been favourable The incidence of complications is 5 6 per cent, which is similar to that of our series Clawson (1964) noted a complication rate of 19 per cent, however when the sliding screw plate fixation was used In the case of the unstable fracture the complication rate is higher of course Thus Clawson (1964) indicated 38 5 per cent and Dimon & Hughston (1967) as much as 51 per cent This has led to the recommendation of medial displacement osteotomy as a routine procedure in the treatment of unstable trochanteric femoral fractures

However, the complication rate in the case of the McLaughlin osteosynthesis can be reduced even further, also in the case of unstable fractures, if the principles of osteosynthesis as suggested by Sarmiento (1963) are followed Cram (1955) reported 13 3 per cent complications and Foster (1958) 21 3 per cent In our series the McLaughlin osteosynthesis has been employed routinely in the case of stable as well as unstable trochanteric fractures, with a complication rate of 11.5 per cent

the fractures healed in an unchanged position In 62 patients, fracture complications occurred as shown in Table 3 This table lists all changes in the fracture or osteosynthesis material, irrespective of their clinical significance The various groups will therefore be discussed separately

*Migration of the nail* occurred in 14 patients In all cases it was a matter of a displacement of only a few millimeters within the head-neck area of the femur, and thus they were all without functional importance

*Penetration of the nail* was seen in eight cases In six of these the nail had been placed too close to the cartilaginous border initially Five of these eight fractures belonged to the group without medial support Four patients had to be re-operated In three of the cases a new McLaughlin osteosynthesis was performed using a shorter nail They healed In the fourth the osteosynthesis material had to be removed 12 months after the procedure because of infection and, due to increasing varus dislocation and pseudarthrosis, a McKee-Farrar arthroplasty had to be carried out 18 months later

*Bending of the nail* occurred in 11 patients In nine the angle was less than [illegible] degrees Two patients with a simultaneous greater bending and loosening of the topbolt needed re-operation In one of these, breakage of the plate was found at the same time

*Varus dislocation because of loosening of the topbolt* was by far the most frequent complication and accounted for 40 cases Of these, 32 patients revealed diastasis of the fracture medially or anteriorly at the immediate postoperative X-ray control In nine patients the varus angle was greater than 20 degrees Seven of these required re-operation —three even twice Two patients refused re operation

*Cutting of the nail*, i e dislocation of the nail in relation to the neck or the head, was apparent in two patients only It was of no clinical significance as it was a matter of 4 5 mm of displacement within the confinements of the femoral head

*Loosening or breakage of the plate* was seen in six cases Two cases of plate breakage had to be re operated In four cases there was displacement of the lowermost screws, but so minimal that the fractures healed with varus displacement of less than 10 degrees

*Varus dislocation after removal of the osteosynthesis material* occurred in two cases of pseudarthrosis

*Pseudarthrosis* was seen in three patients One patient was given a McKee Farrar arthroplasty, another a valgus- and medial displace

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Key words McLaughlin osteosynthesis trochanteric femoral fractures unstable trochanteric fractures

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As can be expected, the number of ideal osteosyntheses decreases with the increasing difficulty of repositioning, and the number of fracture complications increases (15 of 25 patients did not undergo ideal osteosynthesis and represent eight of ten re-operated patients). In spite of this our series shows only 14.8 per cent of the patients with unstable fractures to have had significant fracture complications and only 5.9 per cent of these needed re-operation. These numbers are significantly less ($P < 0.01$) than those indicated by Dimon & Hughston (1967) for osteosynthesis with the Jewett apparatus.

Early weightbearing was found to increase the complication rate (11 of 25 patients with complications bore weight after 6 weeks, leading to varus dislocation of the fracture in seven and penetration in six cases).

*Based on these results we find the McLaughlin osteosynthesis suitable for the treatment of trochanteric femoral fractures, also of the unstable type. Furthermore it is valuable that the operative procedure is rather simple. However, ideal osteosynthesis and no weightbearing for a prolonged period (more than 8 weeks) is to be recommended in unstable fractures.*


## SUMMARY

Of 317 patients with trochanteric femoral fractures, 305 were treated with McLaughlin osteosynthesis. The mortality rate was 14.5 per cent. The postoperative complication rate (35.6 per cent) was dominated by cardiopulmonary (10.6 per cent) and thromboembolic (10.6 per cent) events. Wound infection was found in 3.8 per cent and osteitis in 0.9 per cent. In all, 106 patients had stable fractures according to the Evans classification. Of these, four had to be re-operated due to penetration or a loose bolt. Two hundred and eleven patients (66.6 per cent) had unstable fractures. Follow up of 169 patients showed two-thirds to have healed in unchanged position. Only 14.8 per cent of the 169 patients *had significant fracture complications*, particularly varus dislocation of more than 20 degrees (nine patients) and penetration of the nail (eight patients). A total of 10 patients (5.9 per cent) had to be re-operated because of varus dislocation, broken plate or development of pseudarthrosis after removal of the osteosynthesis material. McLaughlin osteosynthesis is concluded to be a suitable method for the treatment of trochanteric femoral fractures—also of the unstable type.

quadriceps had decreased to strength 1 2 and the power of the left quadriceps to 2–3 EMG showed giant potentials and decrease of number of motor units in both quadriceps muscles and also in the right adductor muscles

*Neurolysis* of the right femoral nerve was performed in July 1968 (Laurent) In the inguinal region firm scar tissue which compressed the femoral nerve was found The nerve was flat and fibrotic The inguinal ligament was incised and the nerve was freed for a length of 10 cm After operation the pain lessened significantly but there was no change in the strength of the quadriceps muscle The patient still had difficulty in walking the right knee sometimes giving away At follow up 1 year later the patient stated that the pain had lessened still further and was sometimes entirely absent The power of the right quadriceps muscle had not altered during the observation time The patient died in 1972 of cardiovascular disease

*Case* 2 A L. A 43 year old truck driver In August 1968 a diagnosis of malignant melanoma of the skin distal to the right costal arch was made The tumour was extirpated and the patient received local pre operative electron radiation therapy (15 MeV 4000 rad) which was repeated post-operatively In January 1969 a metastasis appeared in the right inguinal region and a local excision was done Post operatively the patient was given electron radiation therapy 6000 rad to the right inguinal region In the summer of 1970 the patient had pain which radiated to the front of the right femur A year later the power of the right quadriceps decreased EMG investigation in August 1971 showed giant potentials and a decrease in the number of motor units the strength of the muscle being only 1–2

During the summer of 1972 the pain increased considerably and in September 1972 an intradural injection of phenolglycerin at the level L 3–4 on the right side was given The pain disappeared after this treatment

The patient was treated in November 1972 in the Orthopaedic Hospital of the Invalid Foundation In the right hip there was a flexion contracture of 30° and the right quadriceps muscle was significantly atrophied the strength being 1 Sensitivity had diminished in the front of the right thigh and on the medial side of the leg The patellar reflex was lost but the Achilles reflex was still present Caudal to the inguinal ligament a tender firm infiltrate was found At operation it turned out to be an abscess containing haemolytic streptococci Post operatively no change in the power of the quadriceps muscle was noted and the patient was still unable to extend the knee against gravity Because of this the patient fell in March 1974 and fractured the right patella His general condition was good and no metastases were found

*Case 3* P B A 37 year old translator In March 1966 a total hysterectomy and bilateral oophorectomy was performed because of an epidermal carcinoma of collum uteri The operation was carried out in Havana Cuba Post-operatively she received 34 applications of X ray therapy on the parametria the total dose being 27 200 rad The therapy was given from both front and back Two years later the patient noted a decrease in strength of both quadriceps muscles Because of this she sustained malleolar fractures in 1971 and 1974 The patient was admitted to the Orthopaedic Hospital of the Invalid Foundation in January 1975 Examination revealed hard pigmented infiltrates cranial to both inguinal regions and on both gluteal regions The strength of both quadriceps muscles had decreased to 3 In the left thigh there was a muscle atrophy of 2 cm The patellar reflexes were lacking

Acta orthop scand 46, 804–808, 1975

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# FEMORAL NERVE COMPRESSION SYNDROME WITH PARESIS OF THE QUADRICEPS MUSCLE CAUSED BY RADIOTHERAPY OF MALIGNANT TUMOURS

*A Report of Four Cases*

L E LAURENT

*Accepted 23 ii 75*

Tissue lesion due to radiotherapy which has caused compression of the femoral nerve and paresis of the quadriceps muscle is obviously rare because no reports on this complication have been found in the literature Similar lesions in the upper limbs caused by compression syndrome of the brachial plexus following treatment by radiation of cancer of the breast have been reported (Westling et al 1968, 1972, Mumenthaler 1964, Stoll & Andrews 1966, Notter et al 1970) Also there have been a few reports of femoral nerve injury in connection with vaginal hysterectomy (Hopper & Baker 1968)

Because the syndrome is little known and the diagnosis and treatment are of orthopaedic interest, it seems relevant to report the following four cases

## CASE REPORTS

*Case 1* I G A 67 year old former secretary was operated in July 1962 with a total hysterectomy and bilateral oophorectomy because of an adenomatous grade II carcinoma of the uterus Postoperatively she received pendel convergence X ray therapy on both parametric regions for 3 months the deep dose was 3 600 rad and filter 0 2 Cu was used on both sides After december 1963 the patient was bothered by persistent radiating pain in front of the right femur Early in 1964 a decrease of the power and atrophy of the right quadriceps muscle was noted Since 1967 there had also been a slight pain in front of the left femur The patient was first seen in the Orthopaedic Hospital of the Invalid Foundation in April 1968 Examination revealed hard infiltrates cranial to both inguinal regions Manual compression of these infiltrates caused radiating pain in front of the femora There was a 3 cm atrophy of the right thigh The patellar reflexes were lacking bilaterally but the Achilles reflexes were present Sensitivity was normal The power of the right

2 months treatment with cortisone and oxiphenbutazone The quadriceps power gradually returned in the course of 6 months

In the first three cases it seems to me that it was the fibrosis due to the radiotherapy which gradually led to compression of the femoral nerve In the first case the radiation dose was relatively small but at operation the femoral nerve was obviously compressed by X ray damaged scar tissue The patient died 4 years later of cardiovascular disease No metastases were found at autopsy

In the third case the total dose of radiotherapy, *27,200 rad* was unusually large

In the fourth case the question is open as to whether the transitory nerve compression syndrome was caused by radiotherapy as the dose was relatively small The patient died 5 years later of metastases of the liver An exploratory laparotomy performed 2 years previously had not revealed any signs of metastases

The related compression syndrome of the femoral nerve seems to be of orthopaedic interest both clinically and therapeutically, because pain may be relieved by an operative decompression of the nerve Function of the quadriceps muscle however does not seem to improve

A change in the technique of radiation therapy is possibly needed In giving radiation in doses large enough to be effective the risk of such complications probably cannot be entirely eliminated (Westling et al 1968)

## SUMMARY

Four patients showed signs of femoral nerve compression with subsequent paresis of the quadriceps muscle after radiation therapy of malignant tumours The compression was caused by scar tissue due to radiation treatment of the inguinal region The first symptom was radiating pain in the front of the thigh and lower leg which appeared 12 16 months after X ray treatment A decrease in the strength of quadriceps muscle occurred some months later

In one case the femoral nerve was decompressed another patient was treated by an intradural phenolglycerin injection and one patient was treated with cortisone and oxiphenbutazone In these cases the pain decreased considerably but in one case only the paresis of the quadriceps muscle improved after treatment

bilaterally Sensitivity was decreased bilaterally in the front of the thigh and on the medial side of the leg EMG showed giant potentials and a decrease in number of motor units in both quadriceps muscles She had no pain A neurolysis was considered but postponed

*Case 4* A E A 53-year-old nurse The patient had a hysterectomy in 1959 due to *myomatosis* *A bilateral* salpingo oophorectomy was performed in *April 1962* because of malignant cystadenoma of the right ovary Post operatively the patient received pendel convergence X ray therapy, 3000 rad, filter 0 2 Cu on both parametric regions She had, in addition, steady field treatment on the umbilical region, the deep dose being 1,848 rad, filter 1 0 Cu She was also treated with Sendoxan In December 1962 a painful infiltrate occurred cranial to the right *inguinal region The tumour which was situated in the internal oblique* muscle was extirpated (Laurent) PAD· Partly necrotised muscle tissue damaged by radio therapy No metastases were seen in the peritoneal cavity In May 1963 the patient noticed pain in the front of the right femur and a slight decrease in the power of the right quadriceps muscle In August the pain had increased and radiated to the medial side of the leg The strength of the quadriceps muscle was 3 Prednisolone 4 mg daily, and oxiphenbutazone 300 mg daily, were prescribed for 2 months During the treatment the pain disappeared and in May 1964 the power of the quadriceps muscle was almost normal In 1968 the patient died of metastases in the liver

## DISCUSSION

Each of the four patients received radiation treatment of the inguinal region because of malignant tumours In my opinion the fibrosis following X-ray treatment caused compression of the femoral nerve The first symptom of nerve compression was pain radiating in the front of the thigh and the medial part of the lower leg Three of the four patients had pain Several months after the pain began, a decrease in the power of the quadriceps muscle occurred, and three of the patients had difficulty in walking One patient got a patellar fracture and another suffered malleolar fractures due to the palsy of the quadriceps muscle EMG investigation in three cases showed typical *signs of peripheral lesion of the femoral nerve*

In the first case, a decompression of the femoral nerve was performed and it was seen to be compressed by scar tissue Pain greatly decreased after operation, but paresis of the quadriceps muscle remained unchanged In the second case a very severe pain disappered after intradural phenolglycerin injection The palsy of the quadriceps muscle here seems to be permanent, and decompression of the femoral nerve will hardly lead to further improvement The third patient is painless, a decompression operation is considered but postponed In the fourth case, with only moderate symptoms, the pain disappeared after

2 months treatment with cortisone and oxiphenbutazone The quadriceps power gradually returned in the course of 6 months

In the first three cases it seems to me that it was the fibrosis due to the radiotherapy which gradually led to compression of the femoral nerve In the first case the radiation dose was relatively small, but at operation the femoral nerve was obviously compressed by X ray damaged scar tissue The patient died 4 years later of cardiovascular disease No metastases were found at autopsy

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A change in the technique of radiation therapy is possibly needed In giving radiation in doses large enough to be effective, the risk of such complications probably cannot be entirely eliminated (Westling et al 1968)

## SUMMARY

Four patients showed signs of femoral nerve compression with subsequent paresis of the quadriceps muscle, after radiation therapy of malignant tumours The compression was caused by scar tissue due to radiation treatment of the inguinal region The first symptom was radiating pain in the front of the thigh and lower leg which appeared 12 16 months after X ray treatment A decrease in the strength of quadriceps muscle occurred some months later

In one case the femoral nerve was decompressed another patient was treated by an intradural phenolglycerin injection and one patient was treated with cortisone and oxiphenbutazone In these cases the pain decreased considerably, but in one case only the paresis of the quadriceps muscle improved after treatment

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2 months' treatment with cortisone and oxiphenbutazone. The quadriceps power gradually returned in the course of 6 months.

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The related compression syndrome of the femoral nerve seems to be of orthopaedic interest, both clinically and therapeutically, because pain may be relieved by an operative decompression of the nerve. Function of the quadriceps muscle, however, does not seem to improve.

A change in the technique of radiation therapy is possibly needed. In giving radiation in doses large enough to be effective, the risk of such complications probably cannot be entirely eliminated (Westling et al. 1968).

## SUMMARY

Four patients showed signs of femoral nerve compression with subsequent paresis of the quadriceps muscle, after radiation therapy of malignant tumours. The compression was caused by scar tissue due to radiation treatment of the inguinal region. The first symptom was radiating pain in the front of the thigh and lower leg which appeared 12–16 months after X-ray treatment. A decrease in the strength of quadriceps muscle occurred some months later.

In one case the femoral nerve was decompressed, another patient was treated by an intradural phenolglycerin injection and one patient was treated with cortisone and oxiphenbutazone. In these cases the pain decreased considerably, but in one case only the paresis of the quadriceps muscle improved after treatment.

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*Key words* femoral nerve compression paresis of the quadriceps muscle complication of radiotherapy

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Acta orthop scand 46 809 822 1975

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# CHONDROMALACIA OF THE PATELLA

## *Incidence, Macroscopical and Radiographical Findings at Autopsy*

J Stougård

Accepted 28 1 75

Cartilaginous changes on the patella generally known as chondromalacia of the patella were first described as a clinical entity by Budinger (1906) Numerous authors (Heine 1926 Silfverskiold 1938, Owre 1936 Darrach 1939 and Wiles et al 1956) have reported on its early and common occurrence on the basis of post mortem as well as operative findings The aetiology is uncertain and it has not yet been definitely elucidated whether or not the condition is closely related to osteoarthritis Wiberg (1941) related the cartilaginous changes to the shape of the patella and to the articulation with the femur thus suggesting a mechanical factor In Darracott & Vernon Roberts (1971) opinion the primary cause is to be found in the underlying trabecular bone possibly as a result of derangement of the blood supply

The purpose of the present study was to ascertain the incidence of chondromalacia of the patella and to determine the site and extent of the cartilaginous changes and their relation to the radiological changes

## MATERIAL AND METHOD

The material comprises 59 autopsies on 38 male and 21 female persons all of whom died below the age of [illegible] This upper age limit was fixed in order to avoid the osteoarthritic changes of senescence in the knee joint as a whole and their possible secondary influence on the patella Knee joints with changes following fractures inflammation etc were also excluded Death was due to violence in [illegible] cases heart disease in 14 and in 16 cases it was due to various surgical and medical diseases none of which could be classified as joint diseases

All post mortem examinations of the knee joints were performed by the author through a wide medial incision After inspection of the joints the thickness of the cartilage on the patella femur and tibia was measured with a slide gauge Both patellae with a surrounding rim of synovial membrane and joint capsule were

excised and described macroscopically, and tissue from normal and altered synovial membrane cartilage, and bone was removed for microscopic study

The last 60 patellae removed were x rayed (before the specimens were taken) in the a p view and the tangential view—the projection used clinically with the lower pole of the patella against the film and the beam parallel to the patella joint surface (the so called conventional tangential view) Finally slices 2 mm thick containing both cartilage and bone from areas with macroscopically normal cartilage and also from areas with abnormal cartilage were sawn in a horizontal plane using an electric saw These slices were x rayed at right angles to the sawn surface (using 40 kV and 10 mA at a focal distance of 90 cm and film type Gevaert Curix Rapid)

## RESULTS

The main emphasis will be placed on the macroscopic appearance of the patella and its relationship to the radiological findings The microscopic specimens were studied, but as the changes found were in accordance with previous work (Øwre 1936 and Wiles et al 1956) they will not be mentioned further here

### *Macroscopic findings*

The cartilage-lined posterior surface of the patella may be described roughly as oval with the inferior arch drawn downwards at the lower

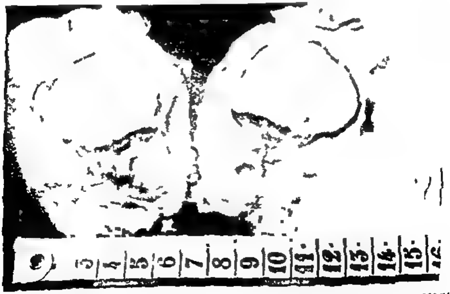



*Figure 1 R and L patellae from a 43 year old man Cartilage macroscopically normal Medially the synovial fold covers part of the cartilage Distally the bone is without cartilage*

*Table 1 Distribution by sex and age of 118 knees with and without cartilaginous changes on the patella. The area involved on the medial (M) and lateral (L) facet in mm²*

| Sex | Age (years) | Number of knees | Normal cartilage |  | Area with cartilaginous changes |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  | <100 mm² |  | 100–200 mm² |  | >200 mm² |  |
|  |  |  | M | L | M | L | M | L | M | L |
| Male | 10–19 | 8 | 6 | 6 | 0 | 1 | [illegible] | 1 | 0 | 0 |
|  | 20–29 | 14 | 4 | 8 | 5 | 6 | [illegible] | 0 | 3 | 0 |
|  | 30–39 | 18 | 5 | 11 | 6 | 6 | 3 | 1 | 4 | 0 |
|  | 40–49 | 30 | 5 | 9 | 8 | 20 | 16 | 6 | 7 | 1 |
| *Female* | *10–19* | *4* | *2* | *4* | *2* | *0* | *0* | *0* | *0* | [illegible] |
|  | 20–29 | 10 | 4 | [illegible] | 3 | 4 | 1 | [illegible] | 2 | 0 |
|  | 30–39 | 10 | 4 | 6 | 3 | [illegible] | 3 | [illegible] | [illegible] | [illegible] |
|  | 40–49 | 18 | [illegible] | 6 | 7 | 4 | 8 | 5 | 3 | 3 |
| Total |  | 118 | 30 | 56 | 34 | 43 | 35 | 15 | 19 | 4 |

pole of the patella. Distally and medially the cartilage does not reach the *margin*; at this site the bone is covered with synovial membrane from which a flap may extend over the joint surface, even in cases with macroscopically normal cartilage (Figure 1).

The joint surface is divided by a sagittal ridge into a smaller medial and a larger lateral facet. The medial joint surface may be divided by yet another sagittal ridge. This was so in five male and nine female patellae (bilaterally in five). In seven patellae (one male and six female) there was a transverse ridge slightly inferior to the middle and most distinct on the medial half.

Cartilage thickness was measured proximally and distally on both facets and on the sagittal ridge in areas with macroscopically normal cartilage. The maximum value, 4.0 mm, was measured medially in a 1[illegible]

[illegible] mm, 2.6 mm and 2.[illegible] mm respectively in the male group and 2.5 mm, 2.4 mm and 2.4 mm in the female group. The equivalent mean values for both sexes were 2.7 mm, 2.7 mm and [illegible].9 mm in the youngest age group and 2.5 mm, 2.4 mm and 2.5 mm in the oldest.

Corresponding measurements on the patellar joint surface of the femur and on the weight-bearing surfaces of the femur and tibia

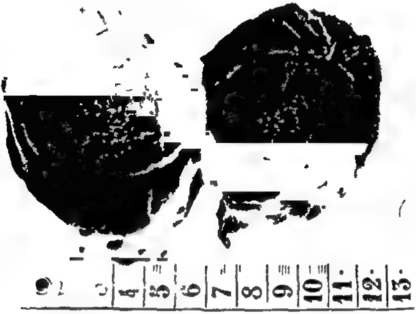


*Figure 2. R. and L. patellae from a 40 year old man. Considerable cartilaginous changes with deep fissures and flaking on both articular facets.*

*Table 2. Distribution of the macroscopic cartilaginous changes by sex and age*

| Sex | Age (years) | Number with degeneration | Oedema | Fissuring | Fraying | Fissuring to the bone | Naked bone |
|---|---|---|---|---|---|---|---|
| Male | 10–19 | 2 | 2 | 1 | 0 | 0 | 0 |
| | 20–29 | 10 | 9 | 1 | 2 | 2 | 2 |
| | 30–39 | 13 | 13 | 7 | 5 | 0 | 0 |
| | 40–49 | 31 | 29 | 19 | 13 | 3 | 3 |
| Female | 10–19 | 2 | 2 | 0 | 0 | 0 | 0 |
| | 20–29 | 6 | 6 | 2 | 1 | 0 | 0 |
| | 30–39 | [illegible] | 6 | 2 | [illegible] | [illegible] | [illegible] |
| | 40–49 | 18 | 17 | 11 | 13 | 4 | 3 |
| Total | | 88 | [illegible] | 43 | 36 | 9 | [illegible] |

ranged from 1.9 to 4.1 mm, with mean values 2.5 mm, 3.1 mm, and 2.6 mm, respectively.

The thickness of the altered cartilage on the patella ranged from 0.0 mm to 6.0 mm, the high values being found in areas with considerable oedema of the cartilage.

*Pathological changes in the cartilage* The changes in the patellar cartilage on the medial and lateral facets were determined, and the size of the involved area, as distributed by sex and age group, is given in Table 1 The changes were equally common in females and males and showed a greatly increasing frequency with advancing age In most cases the alterations were bilateral, involving the medial more often than the lateral facet In all cases with changes on the lateral facet the medial facet was also involved

The site on the joint surface was usually distal or distal as well as proximal, and changes were more rarely seen on the proximal half only

The area of altered cartilage was largest on the medial facet Thus, 19 patellae with medially situated changes were in the group with the largest area (exceeding 200 mm²), whereas this applied to only four with laterally localized changes

The severity of the cartilaginous changes ranged from oedema by way of fissuring, with or without flaking (Figure 2), to denuded bone (Table 2) The most severe changes were found medially Oedema was present in practically all cases With advancing age the changes became more pronounced, and this applied particularly to females Loose flakes of cartilage were not observed in any case

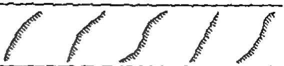
*In addition to the more centrally located cartilaginous changes, 33 patellae also had changes in the most medial location, covered with a fold of the synovial membrane* This was also found on three patellae with no other cartilaginous changes

*Radiological findings*

The last 60 patellae removed were also examined by radiography A large number of them were from the older age groups and had a higher incidence of cartilaginous changes than the total series (only eight patellae being entirely devoid of cartilaginous changes and another eight having changes only on the medial articular facet)

The distribution according to sex was 44 patellae from males and 16 from females

The curve of the joint surface was easier to assess directly from a conventional tangential view than from macroscopic examination, the result of which it corresponded in all essentials Figure 3 gives the distribution according to a number of depicted profiles In the above-mentioned eight patellae with macroscopically normal cartilage the medial facet was straight or slightly concave and the lateral one con-



| | | | | | |
|---|---|---|---|---|---|
| MEDIAL | 18 | 10 | 21 | 6 | 5 |
| LATERAL | 0 | 0 | 0 | 5 | 55 |

*Figure 3 Grouping of patellae by the curve of the joint surfaces assessed radiologically*

case In 10 patellae the medial facet was divided into two smaller facets On macroscopic study five of these cases showed a longitudinal ridge and the other five a centrally localized prominence on the medial facet

Patellar slices from the central and widest part of the patella exhibited largely the same curve of the articular facets as did the con

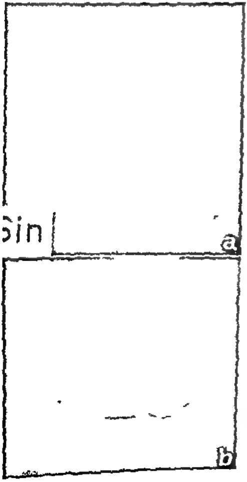
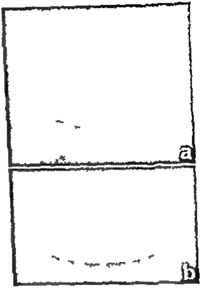



*Figure 4 a X ray film of slices sawn proximally and distally from the same patella originating from a 49 year old woman The curve and the termination medially of the medial joint surface differ on the two slices The distal one shows cartilaginous changes*
*b X ray film of a patellar slice from a 47 year old woman Cartilaginous changes on both articular facets most pronounced laterally Osteophyte formation medially as well as laterally*

*Figure 5 a X ray film of a patellar slice from a 29 year old man Cartilaginous changes medially on the osseous prominences*
*b X ray film of a patellar slice from a 44 year old woman Cartilaginous changes only medially on the osseous prominences On the lateral articular facet the cartilage is macroscopically normal Distinct densification of the bony structure at this site*



ventional tangential view of the whole patella Slices from the proximal, and especially from the distal narrower part of the patella sometimes showed a different surface curve with increased convexity and a more abrupt ending medially (Figure 4 a) In the conventional tangential view of the entire patella this may create an illusion of a prominence on the joint surface, especially if the lower pole is slightly tilted On the other hand small prominences visible on the patellar slices may disappear in the conventional tangential views

The patellar slices showed an uneven joint surface curve only medially but it was not possible on a radiograph of a single slice to ascertain whether there was a longitudinal ridge or a more localized prominence In 28 patellae out of the 60 such osseous changes were present and 18 of them had macroscopic cartilaginous changes at the same level (visible also on the X ray films of the patellar slice (Figure 5 a & b)) In the other 10 the cartilage proceeded across the osseous prominence with the same thickness forming a cartilaginous prominence

To gain an impression of the relationship between the joint facets on the patella the lengths of the medial facet $m$ and of the lateral facet $l$ were measured on the conventional tangential films, and the ratio $m/l$ between the two was determined The ratio differed between the extremes 0 51 and 0 89, with a mean value of 0 72 Thus the medial facet

*Figure 8 a X ray film of the R patella from a 47 year old woman Cartilage macroscopically normal Skeletal structure less dense medially than laterally*
*b X-ray film of a patellar slice from a 43-year old man Cartilage macroscopically normal It manifests itself as an approx 2 mm thick layer on top of the bony surface The bony structure shows distinct densification laterally*

was never larger than the lateral one, and never smaller than half the lateral one There was no difference between sides The angle P, with vertex at the top of the sagittal ridge and the sides passing through the medial and lateral corners of the articular surface, was measured The mean value was 133 5°, with minimum value 116 4° and maximum value 145 2° Here too there was no difference in the mean values between the sides A comparison of these values, including localization, extent, and severity of the cartilaginous changes, failed to reveal any definite relationship

*Bone density* When estimating the density of bone in the patella, the shape of the joint surfaces may be of some importance The lateral facet makes up a more even, smoother surface, parallel to the X-ray beam in the conventional tangential view, than the convex, perhaps somewhat humpy medial facet The beam will, therefore, pass laterally for a greater distance through the more compact bone at the base of the cartilage, giving the impression of greater skeletal density (Figure 6 a) Even in cases with extensive cartilaginous changes medially, the conventional tangential views never showed a bony density medially, or sclerosing, as pronounced as on the corresponding lateral facet (where the cartilaginous changes were not present or were usually less marked) The lateral facet, on the other hand, exhibited among the

oldest subjects increased bony density or sclerosing under cartilaginous changes sometimes with denuded bone

Radiography of the patellar slices may afford a better picture of the density because of the straighter and more equal distance the X ray beam has to pass in the medial and lateral halves of the patella However such slices with macroscopically normal cartilage still showed an increased bony density on the lateral half most marked centrally and decreasing laterally as well as towards the sagittal ridge In a few patellae this increased density may extend deeper down (Figure 6 b) The slices with macroscopic medial cartilaginous changes showed in 11 patellae a less dense bony structure in eight patellae admixed with small sclerotic fields but only in three patellae a distinctly sclerotic area underneath the cartilaginous changes The remaining 30 patellae with cartilaginous changes and the eight with normal cartilage had no definite skeletal changes medially On the lateral joint surface only one patella with lateral cartilaginous changes showed a less dense bony structure alternating with sclerotic fields Twenty-one patellae had sclerosis of the bone centrally underneath the cartilaginous changes (but this was present also in four patellae with normal cartilage on both facets and in two with normal cartilage on the lateral facet) In the remaining 22 patellae with cartilaginous changes laterally the bony structure did not differ from that in the 10 with normal cartilage

*Bony proliferation* At this point only osteophyte formations will be mentioned not the above mentioned osseous prominences on the joint surface which may also possibly be signs of new bone formation

Osteophyte formation was observed on 12 patellae in the older age groups in the conventional tangential views (on the corresponding patellar slices they could be demonstrated at the same location) The osteophytes measured from 1 to 5 mm and were in all 12 cases located laterally and in two cases also medially Macroscopic cartilaginous changes were present medially in all 12 cases and in 11 cases also laterally

In the case of the patellar slices the osteophytes were present on 22 patellae with location medially on three medially and laterally on 11 (Figure 4 b) and laterally only on eight patellae In both sex groups the osteophytes occurred most often in the oldest age group but among the males they were also seen in the age group 20 29 years (three cases) and in the age group 30 39 years (four cases) In all cases macroscopic cartilaginous changes were found medially and in 17 cases also laterally

*Bony attrition* or defects in the bone surface could not be detected with certainty in the conventional views On the patellar slices it was found in eight patellae medially and in one laterally, most often in the oldest group of males In five of these cases it was situated on top of a bony prominence

## DISCUSSION

The present investigation confirmed the common occurrence of cartilaginous changes on the patella, even in the younger age groups, and a marked increase in this frequency with advancing age There does not seem to be any major difference between the sexes or between sides

Several aetiological theories have been advanced Many authors believe in a traumatic origin (Budinger 1906, Aleman 1928, Hilzensauer 1936, Franke 1971), others in a certain degree of patellar dysplasia (Soto Hall 1945, Bengert 1964, Deburge & Benoist 1972), possibly combined with a tendency towards lateral dislocation of the patella (Macnab 1952, Furmaier 1953, Viernstein & Weigert 1968) Bengert (1964) and Crooks (1967) feel that a prominence at the upper boundary of the patellar joint surface of the femur may be of importance Others have mentioned certain changes in the synovial membrane influencing the nutrition of the cartilage (Sundt 1938, Hirsch 1947) With respect to cartilage thickness the present investigation showed no major difference between the two facets on the patella or other joint surfaces in the knee joint The high values for cartilage thickness which Øwre (1936) measured, in particular medially, were possibly due to appreciable oedema in association with the chondromalacia In an important paper by Wiberg (1941) the shape of the patella was advanced as representing an essential factor He suggested that the articulation of the medial joint surface with the patellar surface of the femur took place on a limited area of the joint surface which was thereby exposed to an exceptionally high weight-bearing stress

The present studies have shown that the medial articular facet is more frequently and more severely involved in the case of cartilaginous changes which are also more pronounced than on the lateral articular facet Macroscopic assessment as well as radiography of the entire patella and of patellar slices showed medially a varying surface curve, most often convex, as opposed to the concave lateral facet Both are to articulate with convex joint surfaces on the patellar surface of the femur

On the basis of the varying shape and in particular size of the medial articular facet, various types of patella may be distinguished (Wiberg 1941, Baumgartl 1966) In the present paper this is expressed by the ratio $m/l$ between the lengths of the medial and lateral facets and was found to range from 0 5 to 0 9 No definite relationship was found between the size of this ratio and the cartilaginous changes Moreover, the medial facet may also show the most marked longitudinal and transverse ridges Together with the osseous prominences observed on the patellar slices, these ridges could compromise satisfactory articulation and thereby cause abnormal stress on the cartilage

Harrison et al 's (1953) theory of lack of weight-bearing as a possible cause of cartilaginous degeneration can perhaps explain the common occurrence of cartilaginous changes in the extreme peripheral part of areas which do not take part in normal articulation

Changes in the bony structure are important criteria for making a diagnosis of osteoarthritis from the X ray film (Ahlbäck 1968) The conventional tangential view shows, in cases with normal cartilage, a less dense bony structure medially than laterally (where there may be densification of the bone just underneath the joint surface) Even in the presence of fairly marked cartilaginous changes medially, these films (which are standard exposures according to clinical practice) cannot show definite sclerosis medially Sclerosis occurred only laterally, where the cartilaginous changes were far less marked These findings were confirmed using the films of the patellar slices and were most distinct in the *presence of cartilaginous changes but observed also in* cases with macroscopically normal cartilage Thus, the patella may be the seat of fairly severe cartilaginous changes which do not give rise to demonstrable bony changes on the X ray film in the form of sclerosis If the changes progress, however, clinical experience has shown that the marked femoro patellar osteoarthritis will manifest itself on the X ray film as sclerosis of the adjacent bony surfaces Presumably, most of these cases indicate a condition which has *persisted* for years and which has caused to a greater or lesser extent a disappearance of the cartilage

Osteophyte formation has previously been regarded as an important criterion for the radiological diagnosis of osteoarthritis, and Billing (1942) considered it to be a definite sign of patellar chondromal[illegible]

[illegible] osteophytes were scanty on the conven-

tional tangential films, often localized laterally, and increasingly common with advancing age On the patellar slices they were seen more often, but the majority were only 1 mm to 2 mm in length This is no doubt the explanation of why they did not manifest themselves on the conventional films Cartilaginous changes were present in all these cases This, however, cannot form the basis for establishing whether they are conditioned by advancing age or by cartilaginous changes which were present, as stated already, on practically all patellae from the older age groups Even so, it should be mentioned that the few patellae with normal cartilage did not exhibit osteophytes in any of the radiographic exposures

*From what has been stated above it may be concluded that cartilaginous changes on the patella are common* Aetiological factors are presumably numerous The cartilaginous changes are most pronounced on the medial facet, and a mechanical factor caused by the convex shape of the medial facet, with simultaneous osseous prominences located centrally on this joint surface, may be contributory The skeletal structure under the cartilaginous changes does not always show the expected sclerosing, particularly not on the medial joint surface Thus, the absence of bony changes on the X-ray films does not necessarily indicate absence of cartilaginous changes on the patella The occurrence of osteophytes is scanty even in the presence of the cartilaginous changes They are most often localized laterally, where cartilaginous changes are least marked Accordingly, only very cautious conclusions can be drawn from the absence or presence of osteophytes Nevertheless, it should be mentioned that cartilaginous changes were present in all cases showing osteophytes

## SUMMARY

In a post mortem series of 59 persons aged 10 50 years, 91 of the 118 patellae exhibited cartilaginous changes These changes were *most common* in the older age groups and usually affected the medial articular facet where they were also most extensive and most profound Clinical and radiological assessment showed this facet to be less suited to articulation with the femur because of its convex joint surface, central ridges, and prominences

Radiography using tangential views of the entire patella and of 2 mm thick slices of the patella showed in cases with macroscopically *normal* cartilage a less dense bony structure medially and a denser structure

laterally Even in the presence of distinct cartilaginous changes this difference in bone density did not alter essentially In particular, there was no definite sclerosing medially, where the changes in the cartilage were most marked Osteophyte formation was sparse, but most common in the older age groups, and laterally Osteophytes were seen only on patellae with cartilaginous changes

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*Key words* : chondromalacia patellae osteoarthritis, patella, knee joint femur patellar joint

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Acta orthop scand 46 823-833, 1975

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# 150 OPEN FRACTURES OF THE TIBIAL SHAFT—THE RELATION BETWEEN NECROSIS OF THE SKIN AND DELAYED UNION

P A TØNNESEN, J HEERFORDT & M PERS

Accepted 22 iv 75

In this paper an attempt is made to assess the influence of soft-tissue trauma and treatment on the healing of open fractures of the tibia The development of skin necrosis has been taken as evidence that the soft tissue treatment has been inadequate

## MATERIAL AND METHODS

The material consists of 150 consecutive, open fractures of the tibial shaft treated at Department M Bispebjerg Hospital Copenhagen during the years 1958–1970 inclusive Only diaphyseal fractures are included, all fractures involving the knee or ankle joints having been ruled out Multi traumatized patients and patients who for other reasons cannot be evaluated in this connection have likewise been excluded There were 43 women and 107 men The average age was 44 years (range 15 84 years)

### *Classification of trauma*

The material has been divided into two groups according to the severity of trauma using the classification proposed by Bauer et al (1962) and adopted by Edwards 1965 (Table 1

*Group 1* Direct high energy trauma to the lower leg This group which consists of 139 fractures comprises all cases in which a motor vehicles were involved (74 motor cars 35 motorcycles and 16 light motorcycles totalling 125 fractures), b the victim fell from a height of more than 3 meters (8 fractures), and c the lower leg was hit by a direct blow from a heavy object (5 fractures)

*Group 2* Indirect low energy trauma caused by forces arising from the human body itself for instance torsional trauma or from other forces of comparable magnitude This group consists of 11 fractures caused by a falls from table or chair 7 fractures b falls while playing football (2 fractures), and c falls with a bicycle 2 fractures)

*Table 1 Severity of trauma (according to Bauer et al 1962)*

| | Low-energy | High energy | Total |
|---|---|---|---|
| Bauer et al | 10 | 82 | 92 |
| Edwards* | 4 | 114 | 118 |
| Our material* | 11 | 139 | 150 |

*Classification of soft-tissue injury*

We have adopted the following classification which has been used by several writers (Veliskakis 1959, Matter 1970, Hamza et al 1971, Olerud & Karlstrom 1972) (Table 2)

*Grade 1* Puncture wounds 'from within' or small lacerations up to about 2 cm in length with no loss of skin and minimal muscle damage (19 fractures)

*Grade 2* Larger wounds over 2 cm in length with contusion of the adjacent skin and some muscle damage (75 fractures)

*Grade 3* Severe crush injuries with extensive damage to the skin and muscles (56 fractures)

It must be noted that all the patients with low energy trauma had Grade 1 lesions of the soft tissue, whereas nearly all of the patients subjected to high energy trauma had lesions of Grades 2 or 3

*Classification of fracture type*

The anatomical fracture *level* has been classified according to the method used by Olerud & Karlstrom (1972) as follows

1) Proximal metaphysis — 7 cases
2) *Diaphysis* — 118 cases
3) Diaphysis + distal metaphysis — 25 cases

The fracture *types* have been divided according to the classification proposed by Edwards (1965) as follows

1) Transverse fractures This group comprises
   a) simple transverse fractures — 66 cases
   b) all comminuted fractures with one or more intermediate fragments, including 12 double fractures — 74 cases
   Totalling 140 transverse fractures
2) *Longitudinal fractures all other fractures a total of* — 10 cases

*Fracture healing*

In this study we have arbitrarily defined union as having occurred when weight bearing without plaster cast was possible

*Treatment*

A total of 96 fractures, 64 per cent of the material, were given conservative treatment consisting of soft tissue revision, fracture reduction, and the application

*Table 2 Soft-tissue lesions (according to Veliskakis 1959)*

| | Number of patients | Per cent |
|---|---|---|
| Grade 1 | 19 | 13 |
| Grade 2 | 75 | 70 |
| Grade 3 | 56 | 37 |
| Total | 150 | 100 |

Grade 1 Wounds less than 2 cm, no skin loss
Grade 2 Wounds over 2 cm and contusion of skin/muscle
Grade 3 Severe crushing, extensive contusion/loss of skin and muscle

of a (split) plaster cast, in many instances supplemented by wire traction through the heel The treatment has been somewhat more conservative than in Bauer et al.'s series (1962) in which only 45 per cent were treated conservatively or in Edwards' series (1965), in which 50 per cent were treated conservatively

A further 54 patients were treated by operations of the following types 25 plate osteosyntheses of the Lane type, 17 Rush-pin fixations, 6 screw fixations and 1 fixation by cerclage wire There were 5 fixations with Kirschner wires incorporated in plaster casts These have been counted as operations, but they might as well have been included in the group of conservatively treated cases Nine operations were carried out as secondary procedures from 5 to 36 days after the original trauma (average 18 days)

The incidence of operative treatment in relation to the degree of soft-tissue injury is seen in Figure 1

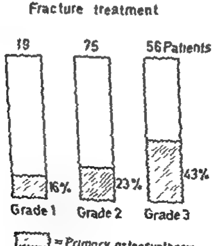


*Figure 1 The distribution of conservative and operative treatment in the material*

*Table 1 Severity of trauma (according to Bauer et al 1962)*

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In this study we have arbitrarily defined union as having occurred when weight bearing without plaster cast was possible

*Treatment*

A total of 96 fractures 64 per cent of the material were given conservative treatment consisting of soft *tissue revision* fracture reduction and the application

## RESULTS

Among 23 patients in whom the wounds were allowed to heal by secondary intention there were no cases of skin necrosis, and this was also the case in 41 of the remaining patients irrespective of the method of soft tissue closure (Table 3). It must be pointed out that none of the instances of skin necrosis mentioned in Table 3 indicated failure of skin grafting but rather were due to a too optimistic assessment of the viability of the traumatized and oedematous skin at the time of primary treatment.

Delayed primary suture was undertaken in seven cases which all healed uneventfully.

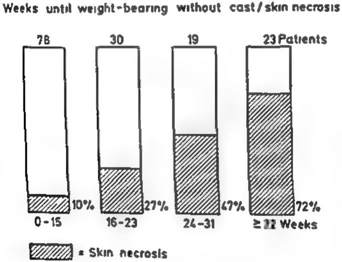



*Figure 3. The relation between the incidence of skin necrosis and the time for fracture healing defined as weightbearing without a plastercast*

*Table 4. Fracture type/treatment/skin necrosis*

| Transverse fractures | Primary osteosynthesis | | No primary osteosynthesis | |
|---|---|---|---|---|
| | Total No | Skin necrosis per cent | Total No | Skin necrosis per cent |
| Simple | 21 | 43 | 45 | [illegible] |
| Comminuted | [illegible] | 33 | 53 | 25 |
| Total | 42 | 38 | 98 | 23 |

*Table 3 Soft tissue treatment*

| | Number of patients | Secondary skin necrosis |
|---|---|---|
| No suture | 23 | 0 |
| Simple suture | 92 | 32 |
| Free graft | 9 | [illegible] |
| Relaxing incision + free graft | 22 | 6 |
| Pedicle flap + free graft | 4 | 1 |
| | *150* | *41* |

Smaller wounds were left open for healing by secondary intention whereas larger wounds were closed. Relaxing incisions and skin grafting on primary and secondary defects were used to a certain extent (Table 3).

The primary treatment was carried out by senior registrars, about 20 in number over the 12 years covered by this paper. They all had several years of training in general surgical and orthopaedic departments but none of them had had any regular plastic surgical training.

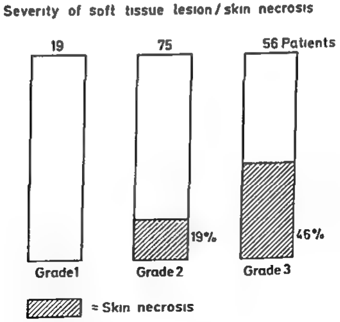



*Figure 2 The incidence of skin necrosis in relation to the degree of soft tissue injury (Grades 1, 2 & 3).*

fracture fixation The alternative principle has been adoped by the representatives of the Swiss A S I F group (Willenegger 1967 & 1972 Maller 1970 Allgower 1971) and by others, notably McNeur (1970), Hicks (1971), Ketenjian & Shelton (1972), Olerud & Karlstrom (1972) and Solheim (1973), who tend to maintain that even deep infections will subside if an absolutely rigid fixation can be provided

Infanger et al (1971) reported excellent results in 95 per cent of 230 (predominantly closed) fractures of the lower leg treated according to the A S I F principles 91 per cent of the fractures were caused by indirect low energy violence (skiing) It is interesting to note that only 11 out of 150 fractures in the present material were caused by low-energy violence They are however, too few to form a basis for any conclusions and they will be left out of the following discussion

Nicoll (1964) concluded that five factors comminution wound displacement infection and loss of bone are fundamental when *comparing methods of treatment Edwards (1965) demonstrated the* intimate connection between skin necrosis infection and fracture prognosis These combined findings demonstrate how misleading any discussion of tibial fractures will be if the severity of trauma is not taken into account

*In this* material the results in the more serious lesions (Grades 2 and 3) are rather unsatisfactory, regardless of the type of treatment employed Out of the 96 fractures that were treated conservatively 32 per cent had not healed after 20 weeks In his analysis of 674 conservatively treated patients Nicoll (1964) similarly found that [illegible] per cent *had failed to heal after 20* weeks in the groups that—on the basis of soft tissue lesions and fracture type—were comparable to our Grades 2 and 3 lesions

The relation between fracture type and healing time in cases with

*Table 3 Healing time in transverse fractures with and without skin necrosis*

| Transverse fractures | No skin necrosis | | | | | Skin necrosis | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Weeks | 0 15 | 16–23 | 24–31 | ≥32 | Weeks | 0–15 | 16–23 | 24–31 | ≧32 |
| | No | Per cent | | | | *No* | *Per cent* | | | |
| Simple | 40 | 70 | 15 | 10 | 5 | 19 | 11 | 26 | 26 | 37 |
| Comminuted | 49 | 59 | 25 | 8 | 8 | 20 | 20 | 15 | 20 | 45 |
| Total | 89 | 64 | 20 | 9 | 7 | 39 | 15 | 31 | 23 | 41 |

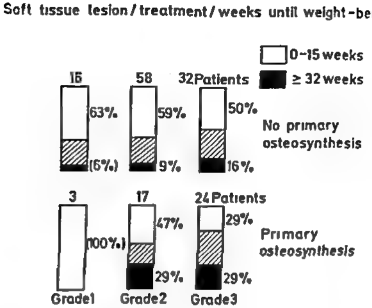



*Figure 4 The relation between the extent of soft tissue injury (Grades 1, 2 & 3) and fracture healing (weeks until weightbearing) in conservatively and operatively treated patients*

The frequency of skin necrosis, totalling 41 cases (27 per cent of the material) increased with the severity of soft-tissue lesion (Figure 2), and the presence of skin necrosis was closely correlated to the occurrence of delayed union (Figure 3)

Skin necrosis occurred in 18 of the 44 cases treated by primary osteosynthesis (41 per cent), whereas only 23 patients out of the remaining 106 cases (22 per cent) developed skin necrosis (Transverse fractures are listed in Table 4)

A comparison of the results of conservative and operative treatment is seen in Figure 4

There were no amputations

## DISCUSSION

When discussing the treatment of open tibial fractures the main point of contention has been the question of conservative treatment versus operative treatment using metallic implants Most British writers, notably Charnley (1961), Watson-Jones (1962), Nicoll (1964) and Saad (1970) have warned against the use of metallic implants because of the increased risk of infection and non-union, and they have attached greater *importance to soft-tissue treatment than to rigid*

racture fixation The alternative principle has been adopted by the epresentatives of the Swiss ASIF group (Willenegger 1967 & 1972, Ialter 1970, Allgöwer 1971) and by others, notably McNeur (1970), Iicks (1971), Kelenjian & Shelton (1972), Olerud & Karlström (1972) and Solheim (1973), who tend to maintain that even deep infections will subside if an absolutely rigid fixation can be provided

Infanger et al (1971) reported excellent results in 95 per cent of 230 (predominantly closed) fractures of the lower leg treated according to the ASIF principles 91 per cent of the fractures were caused by indirect, low energy violence (skiing) It is interesting to note that only 11 out of 150 fractures in the present material were caused by low energy violence They are, however, too few to form a basis for any conclusions, and they will be left out of the following discussion

Nicoll (1964) concluded that five factors "comminution, wound, displacement infection and loss of bone" are fundamental when comparing methods of treatment Edwards (1965) demonstrated the intimate connection between skin necrosis infection and fracture prognosis These combined findings demonstrate how misleading any discussion of tibial fractures will be if the severity of trauma is not taken into account

In this material the results in the more serious lesions (Grades 2 and 3) are rather unsatisfactory, regardless of the type of treatment employed Out of the 96 fractures that were treated conservatively, 32 per cent had not healed after 20 weeks In his analysis of 674 conservatively treated patients, Nicoll (1964) similarly found that 33 per cent had failed to heal after 20 weeks in the groups that—on the basis of soft tissue lesions and fracture type—were comparable to our Grades 2 and 3 lesions

The relation between fracture type and healing time in cases with

*Table 5 Healing time in transverse fractures with and without skin necrosis*

| Transverse fractures | No skin necrosis | | | | | Skin necrosis | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Weeks | 0–15 | 16–23 | 24–31 | ≧32 | Weeks | 0–15 | 16–23 | 24–31 | ≥32 |
| | No | Per cent | | | | No | Per cent | | | |
| Simple | 40 | 70 | 15 | 10 | 5 | 19 | 11 | 26 | 26 | 37 |
| Comminuted | 49 | 59 | 25 | 8 | 8 | 20 | 20 | 15 | 20 | 45 |
| Total | 89 | 64 | 20 | 9 | 7 | 39 | 15 | 21 | [illegible] | 41 |

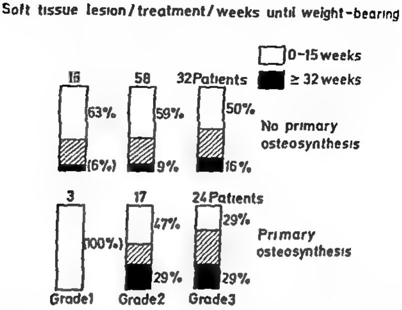



*Figure 4 The relation between the extent of soft-tissue injury (Grades 1, 2 & 3) and fracture healing (weeks until weightbearing) in conservatively and operatively treated patients*

The frequency of skin necrosis, totalling 41 cases (27 per cent of the material) increased with the severity of soft-tissue lesion (Figure 2), and the presence of skin necrosis was closely correlated to the occurrence of delayed union (Figure 3)

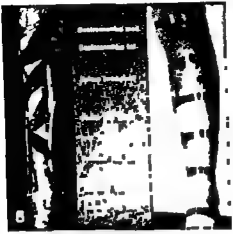
Skin necrosis occurred in 18 of the 44 cases treated by primary osteosynthesis (41 per cent), whereas only 23 patients out of the remaining 106 cases (22 per cent) developed skin necrosis (Transverse fractures are listed in Table 4)

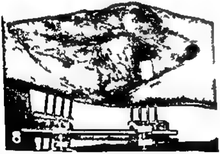
A comparison of the results of conservative and operative treatment is seen in Figure 4

There were no amputations

## DISCUSSION

When discussing the treatment of open tibial fractures the main point of contention has been the question of conservative treatment versus operative treatment using metallic implants Most British writers, notably Charnley (1961), Watson Jones (1962), Nicoll (1964) and Saad (1970) have warned against the use of metallic implants because of the increased risk of infection and non union, and they have attached greater importance to soft-tissue treatment than to rigid





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and without necrosis of the skin is seen in Table 5 Delayed union correlated with necrosis of the skin and not with fracture type

As can be seen in Figure 4, 29 per cent of the fractures treated by primary osteosynthesis, in Grade 2 and 3 lesions respectively, had not united by the 32nd week, while among the conservatively treated cases only 9 and 16 per cent, respectively, had failed to unite

Increasing severity of soft-tissue damage coincided with increased operative activity (Table 1) Increasing severity of fracture type, however, did not 21 simple and 21 comminuted transverse fractures were operated upon, while 45 simple transverse fractures and 53 comminuted ones were treated conservatively In all of the cases treated by primary osteosynthesis some kind of supplementary plaster cast was applied effectively preventing day to-day checking of soft-tissue viability

The striking relation between necrosis and delayed union seen in Figure 3—which is also found in Edwards' study (1965)—certainly seems to be more than a coincidence It is reasonable to assume that the unsatisfactory results in many cases can be ascribed to 1) faulty judgement of soft-tissue viability, 2) further reduction of vascularity by operative intervention, and 3) plaster bandages obscuring the region of interest and making secondary plastic surgical procedures difficult

In A S I F osteosynthesis, plaster casts are not required, but meagre results in severe cases are nevertheless also found in series with compression plates, as shown by Olerud & Karlstrom (1972) who reported 34 per cent 'severe healing disturbances' defined as deep virulent infection, bending and fracture of the plate, refractures skin necrosis and delayed healing' in the group of transverse, open

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*Figure 5 On the right side the lower leg divided into 5 areas On the left the muscles that can be used for myoplasties in these areas dissected out in a cadaver and stained blue*

*Figure 6 Direct high energy trauma resulting in a transverse fracture with extensive damage to the skin The fracture is reduced and immobilized by a Hoffmann apparatus Devitalized skin has been excised Medial part of the soleus muscle has been prepared for myoplasty*

*Figure 7 Primary cover by split skin grafting*

*Figure 8 Appearance after 12 days The grafts have taken*

*Figure 9 Appearance after 10 weeks The Hoffmann apparatus has been removed The fracture has united and the area is covered by muscle and skin*

There is however, no easy short-cut to success in the treatment of the most severe cases Correct estimation of soft tissue viability in the acute stage is admittedly difficult For this and other reasons it has been suggested that all patients with extensive soft-tissue injury and/or bone loss be referred to a 'superspecialist' immediately after the accident (Bauer & Hulth 1973)

The aim of this paper has been to emphasize the importance of adequate soft tissue coverage in primary fracture treatment, and it is suggested that training in plastic surgical techniques should be an integral part of the training of orthopaedic surgeons

## CONCLUSIONS

1 The incidence of skin necrosis rises with the severity of trauma
2 The incidence of delayed union rises with the incidence of skin necrosis
3 The incidence of delayed union is high in conservatively treated cases, but even higher in cases treated by primary osteosynthesis
4 As an alternative treatment of open tibial fractures with skin lesions of Grades 2 and 3, a treatment combining Hoffmann's transfixation and Ger's myoplastic procedures is suggested
5 Close cooperation of orthopaedic and plastic surgeons is recommended

## SUMMARY

In 150 open fractures of the tibial shaft a close relationship between the presence of skin necrosis and delayed union was found The incidence of skin necrosis rose with the severity of trauma It was high (22 per cent) among the fractures that were treated conservatively, but even higher (41 per cent) among those treated with primary osteosynthesis

Neither conventional conservative treatment nor osteosynthesis seems to be satisfactory as a primary treatment of the most severe cases It is instead suggested that external fixation by the Hoffmann Vidal technique should be combined with transposition of viable muscle tissue across denuded fractured bone areas according to the method of Ger

diaphyseal fractures The results published by Olerud & Karlstrom (1972) have been so discouraging that Bauer & Hulth (1973) have proposed that the A S I F compression plates be altogether abolished in tibial fractures In this material intramedullary nailing has not been used, nor did Olerud & Karlstrom (1972) recommend it as a *primary* fixation

For lesions of *Grades 2 and 3 in which internal fixation is undesirable* on account of the additional operative trauma and the risk of infection, and in which plaster casts hamper plastic surgical procedures, primary transfixation according to the method of Hoffmann (1954) seems to be the logical solution This method has been materially improved in later years, and the complications are negligible compared to the obvious advantages offered by the method in cases with severe soft-tissue lesions (Vidal et al 1970, survey by Olerud 1973)

Even though the risk of incurring additional soft-tissue damage through the treatment itself can thus be minimized, the difficult problem of covering a denuded fracture line with vascularized tissue remains Direct suture, even in connection with relaxing incisions, often leads to necrosis (Table 3) Local rotational flaps are notoriously risky on the lower leg, especially in traumatized tissue Cross leg flaps, using Hoffmann's apparatus on both legs, can sometimes be used, but can be technically difficult, are uncomfortable for the patient and are not to be recommended for patients over 50 years of age

One promising method of covering the anterior surface of the tibia *with well vascularized tissue is the technique of muscle transposition* introduced by Ger (1966) Several of the muscles in the lower leg are *able to take over each other's function, making it possible* to transpose one of them across the defect, thus covering the fracture with viable innervated muscle providing ample vascularity around the fracture site (Andersen & Helmig 1970, Barfod & Pers 1970, Barfred & Reumert 1973, Pers & Medgyesi 1973) The transposed muscle belly is then, in its turn, covered with split skin grafts that take without any difficulty, as muscles can be regarded as ideal recipient sites

Only the muscles in Figure 5 can be employed without functional impairment, and the neuro-vascular bundles to the muscles must be carefully *protected* both during the dissection and after-treatment

It should be emphasized that the detrimental effects of an unsuccessful myoplasty are so serious that these procedures should be reserved for experts, preferably *plastic surgeons*

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*Key words* tibial fractures tibial fractures complications fracture fixation tibial fractures soft tissue problems

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## ACKNOWLEDGEMENTS

The authors wish to express their gratitude to Professor E Hart Hansen MD and to Mr Hugh Dovey MD FRCS for their kindness in reviewing and correcting the manuscript

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*Figure 1 Angiograph showing popliteal artery aneurysm, with the jet phenomenon clearly visible*

tion and at a check up 8 months later, when mobility in the knee joint was also normal Pathological examination showed exostosis with remnants of cartilage

## DISCUSSION

In addition to this patient, 18 other cases of traumatic aneurysm caused by cartilaginous exostosis have been reported in the literature Most of the patients were between 16 and 20 years of age which is the age at which the cartilage in the exostosis calcifies (Turek 1967), resulting in a jagged formation that is liable to damage the artery, due either to the latter's pulsation or to movements in the knee joint An important contributary factor is, of course, that just above the knee joint the artery adheres to the tendon of adductor magnus and passes through the narrow opening in this muscle The trauma was located in this area in all but one of the cases referred to above, the exception (Cachera

Acta orthop scand 46, 836–838, 1975

Orthopaedic Department, Gavle Sjukhus, Gävle, Sweden

# ANEURYSM OF POPLITEAL ARTERY CAUSED BY CARTILAGINOUS EXOSTOSIS

## *A Case Report*

LENNART HOVELIUS

Accepted 28 ii 75

*Cartilaginous exostoses which lead to vascular complications in the form of traumatic aneurysm are rare One case was published by Paul in 1953 and subsequent reports of 17 others have been found in the literature*

*In the autumn of 1973 a patient with a traumatic aneurysm in the popliteal artery, caused by cartilaginous exostosis was operated on in our department*

## CASE REPORT

A 17-year-old youth presented with a 2 month history of spontaneous pain in the lower part of the right thigh, with swelling of the soft tissues above the knee after a time He was admitted to the local hospital, where X-ray examination disclosed exostosis distally and medially on the right femur, angiography revealed an aneurysm (Figure 1) He was referred to the Orthopaedic Department, Gävle Sjukhus, where a warm, pulseless resistance the size of an infant's head was observed preoperatively on the medial aspect above the knee, no palpable pulse was noted distally Knee joint mobility was impaired (range 160 90°) The diagnosis was malignant osteocarcinoma and he was operated on The exostosis was exposed, as well as the distal parts of the superior femoral and the popliteal arteries This revealed a false aneurysm with arterial bleeding and old coagulum A hole some millimeters in diameter was found proximally in the popliteal artery, in line with a jagged, broad-based exostosis The exostosis was removed with a chisel and the artery was repaired with 5 0 silk sutures without constriction The postoperative course was uneventful Pulses were readily palpated distally in the lower leg, immediately after the opera-

Acta orthop scand 46 839–847, 1975

Polytechnic of Central London and Middlesex Hospital, London, England.

# THE NEUROPATHIC ULCER AND LOADS ON THE FOOT IN DIABETIC PATIENTS

I A F Stokes, I B Faris & W C Hutton

Accepted 10 v 75

Diabetic patients often develop ulcers on the soles of their feet These ulcers are most common under the second, third and fourth metatarsal heads It is often stated that pressure is the cause of these lesions although there is no quantitative evidence to support this Neuropathy, both motor and sensory, is believed to be the major predisposing factor (Oakley et al 1956, Ellenberg 1968) The sequence of events suggested by Ellenberg (1968) is that clawing of the toes, due to weakness of the small muscles of the foot, leads to excessive loads on the region of the metatarsal heads Callosities occur and small cracks in the skin develop and pass unnoticed because of the sensory neuropathy These cracks develop into ulcers which may extend to involve the underlying tendon sheath and joint

In this study we have measured the load distribution under the feet of diabetic patients and normal subjects to determine if

1 Ulcers occur at sites of maximum load
2 There are changes in the loading of the foot in patients who have never had ulcers which might predispose to the development of ulcers

## GROUPS STUDIED

### *Diabetic patients*

Twenty two patients were studied Each of the patients' feet was classified independently (and before any measurements were made) into one of three groups depending upon the severity of the clinical condition It was assumed that, because of the sensory neuropathy each foot functioned independently, and that an ulcer or callosity on one foot did not alter the subject's gait to the extent of abnormally loading the opposite foot There were seven feet with ray or hallux amputations which were not included in any of the groups, although the unaffected feet of these patients were included in group 2

1970) being an aneurysm caused by exostosis on the proximal part of the humerus.

Treatment is surgery. In most cases the vessel could be repaired with sutures but in some patients an end-to-end anastomosis was performed. A *venous graft (saphena magna)* was used in three cases and an arterial homograft in one. In the latter case there were good pulses distally in the extremity 3 weeks after the operation but they had disappeared after about 6 months. The prognosis was good even if there were no palpable pulses distally after the operation.


## SUMMARY

A case is reported of traumatic aneurysm in a young man, caused by cartilaginous exostosis distally in the femur. An analysis is given of 18 similar cases from the literature.


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*Key words:* aneurysm, exostosis.


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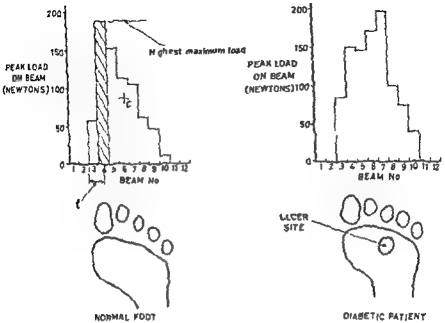



*Figure 1 The peak loading diagram Typical graphs from the analogue system showing the peak load imposed by the forefoot on each beam of the apparatus Footprints are shown in correct register Left a normal subject The centre of the area (the centroid) is marked at C and the position 1 of the highest maximum load is shown These were used to describe foot function in analysing the results Right A patient with a penetrating ulcer Note that the ulcer site corresponds to the position of the greatest maximum load*

reference to the impression of the foot made on the paper the load recorded on individual beams can be attributed to particular areas of the foot (see Figure 1)

Thus for each patient and normal subject two transverse recordings and three longitudinal recordings of load against a base of time were made using the beams, while the relative position of the foot on the beams was found using the inked cloth impression The information was supplemented by the analogue system's picking II the second peak from each longitudinal recording

## RESULTS

The results from the normal group were analysed to test if the measured parameters were influenced by the age or sex of the subjects No significant differences were found, so the 60 normal subjects were considered as one group (Stokes, unpublished results) The results plotted on Figures 2, 3 and 4 show a mean ± 1 s d for each group

The remaining 37 feet were grouped in order of the severity of clinical condition

Group 1 Feet with penetrating ulcers (four feet) or ulcers which had healed with conservative treatment (two feet)

Group 2 The unaffected foot of patients with ulcers (six feet) ray amputations (four feet), or hallux amputations (three feet) It was assumed that most of the factors predisposing to an ulcer were present in these feet

Group 3 Diabetic patients without ulcers but with callosities (18 feet)

Details of the ages and duration of diabetes along with clinical evidence of neuropathy in these patients are shown in Tables 1 and 2

*Normal subjects*

This group consisted of 60 healthy persons of both sexes aged between 16 and 65 years Subjects in this group had no obvious foot or gait abnormalities or assymetries nor any history of foot complaints or treatment

## METHOD

The patients and normal subjects walked barefoot at their normal walking speed along a walkway Recordings of load distribution under the foot were made by means of a load sensitive area in the walkway Details of the apparatus and method have been published by Hutton & Drabble (1972) and Stokes et al (1974) The load sensitive area consists of twelve beams each 400 mm × 12 mm set side by side into the walkway flush with its surface to make an area 400 mm × 144 mm

The vertical component of the total load applied to each beam as the patient walks over it is transduced by means of electrical resistance strain gauges and is recorded on a 12 channel U V recorder Thus a recording against a base of time is made of load on strips of the sole 12 mm wide The load sensitive area in the walkway can be rotated through 90 ° so as to be either longitudinal or transverse to the direction of walking Recordings were made with the apparatus in both configurations from both feet The averages of three longitudinal recordings and two transverse recordings were used to provide a measure of typical load distributions under the foot

The recordings made with the beams longitudinal to the direction of walking always show a peak of loading due to the heel and a peak which occurs during kick off when only the forefoot is in contact with the ground Because we have been concerned with lesions of the forefoot the kick off peaks only are selected and recorded by an analogue system connected to each beam (Stokes et al 1974) and displayed in the form of a stepped graph which shows the distribution of peak loads across the forefoot Typical graphs from a normal subject and a patient are shown in Figure 1

The recordings with the beams transverse to the direction of walking were used to provide a measure of the load carried by the toes alone (except the fifth toe which normally rests on a beam which also carries part of the ball of the foot) The position of the foot relative to the beams is recorded by means of an inked cloth placed over a piece of paper which is positioned in register over the beams By

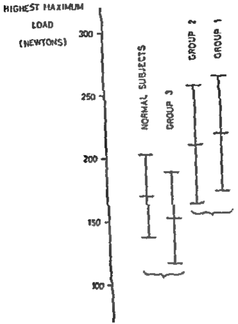



*Figure 3 The greatest maximum load (see Figure 1) and a table of bodyweight for the three groups of patients and the normal group*

Bodyweight (Newtons)

| | Mean | Standard deviation |
|---|---|---|
| Normal | 651 | 128 |
| Group 3 | 618 | 74 |
| Group 2 | 794 | 152 |
| Group 1 | 815 | 163 |

## *Maximum load on the toes*

The value of the maximum load received by the toes was noted in each case by reference to the transverse recordings The mean value ± 1 s d for each group is shown in Figure 4 All three groups of patients were found to impose statistically less load on the toes than the normal group

## *Penetrating ulcers and callosities*

The position of the greatest maximum load was found in each case to correspond to the position of the ulcer in these four patients (see

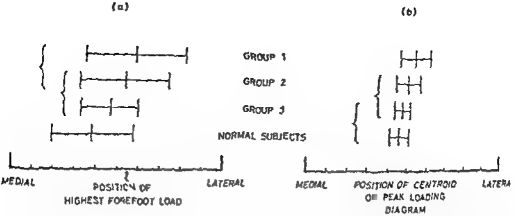



*Figure 2 Results obtained from the peak loading diagram a) The position (l) of the greatest maximum load b) The position of the centroid C of the diagram*

*Groups which are bracketed together are not significantly different at the 5 per cent level*

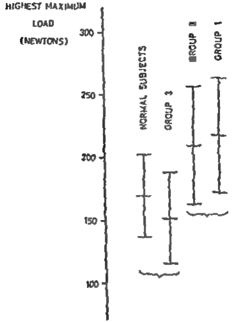
*Peak loading diagram*

For each patient and normal subject, the peak loading diagram as shown in Figure 1 was used to make the following observations

1 The distance (l) from the position of highest maximum load to the edge of the diagram The normal subjects show maximum load occurring more to the medial side of the forefoot, whereas in the patients with ulcers, the maximum load has moved laterally The deviation from normality increases with the severity of the foot condition (see Figure 2 a)

2 The position of the centroid, C", of the diagram (the effective 'centre line' of action of the foot) was found and its distance from the medial edge of the diagram was measured The same trend is shown in that the extent of the deviation from normality increases with the severity of the foot condition (see Figure 2 b)

3 The value of the greatest maximum load was measured in each case (Figure 3) Patients with ulcers have significantly greater maximum loads than the normal group or the patients without ulcers However, the table of bodyweights in Figure 3 shows the same difference, which suggests that the patients with ulcers have areas of greater loading on the forefoot, due primarily to their greater bodyweight

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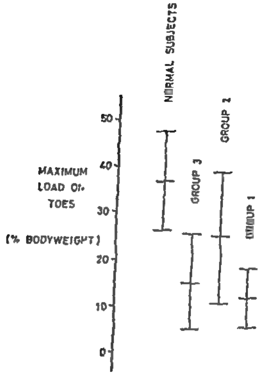


*Figure 4 The maximum recorded load on the toes expressed as a percentage of bodyweight*

Figure 1) This was also the case for two other patients (not included in the groups) who developed penetrating ulcers on the same foot, after "ray" amputations

No exact correspondence was found between the position of the greatest maximum load and the position of a callosity in patients in group 3, although callosities did occur at sites of heavy loading

## DISCUSSION

The apparatus used in this study has provided a sensitive method for the study of loading on the foot The importance of studying the foot during walking has been shown by Stott et al (1973), who demonstrated that in normal subjects the forces under the foot were greater and more localised in walking than in standing The study of patients while walking might therefore provide a more satisfactory method for investigating pathology of the foot

The groups of patients studied represent a spectrum of increasing foot disorder, i e normal, diabetics without lesions, diabetics with lesions The results obtained from this study support this idea In the

*Table 1 Clinical details of patients studied*

| | | Group 1 | Group 2 | Group 3 |
|---|---|---|---|---|
| Age (years) | Mean | 50 5 | 54 4 | 63 4 |
| | Range | 39–66 | 40–70 | 55–68 |
| Duration of diabetes (years) | Mean | 9 0 | 13 6 | 9 0 |
| | Range | 1 17 | 3 26 | 4–15 |

*Table 2 Clinical evidence of neuropathy*

| | Group 1 (6 feet) | Group 2 (13 feet) | Group 3 (18 feet) |
|---|---|---|---|
| *Reflexes* | | | |
| Knee and ankle reflexes | | 2 | 10 |
| Knee reflex present ankle reflex absent | 3 | 5 | 8 |
| Knee and ankle reflexes absent | 3 | 6 | |
| *Sensation* (pinprick test) | | | |
| Intact | | 2 | 10 |
| Loss in toes only | 1 | 5 | 8 |
| More extensive loss in foot/leg | 5 | 6 | |

diabetic patients the position of the maximum load on the foot and the centroid of the peak load diagram are shifted laterally Although these changes are associated with evidence of increasing neuropathy the precise mechanism for their development is not clear but could result from alterations in the balance between inverting and everting muscles of the foot This could be due to weakness of the muscles or to loss of coordination because of loss of afferent impulses from tendon receptors The trends noted probably mean that areas under the lateral metatarsal heads are carrying increased loads as the disorder progresses This would explain the relative infrequency of ulcers under the first metatarsal head

The increasing abnormality in loading on the foot in the three groups of patients corresponds with increasing evidence of neuropathy (Tables 1 and 2) Extensive loss of skin sensitivity was noted in all feet in group 1 and most of the feet in group 2 Deep pain sense was probably equally affected since all the ulcers were painless

The most striking finding is the reduction in load on the toes which is significantly present in the diabetic patients without lesions It is

likely that this is an early result of neuropathy which causes changes in muscle balance by denervation of the intrinsic muscles of the foot These changes have been confirmed by EMG and nerve conduction studies, the results of which will be published separately (Harrison & Faris 1974) This finding supports the sequence of events outlined in the introduction and suggests a mechanism by which load is concentrated on the metatarsal heads and the underlying tissues

This study has demonstrated an area of heavy loading corresponding to the site of the ulcer present in the patients with neuropathic lesions This corroborates the static and semi quantitative results reported by Barrett & Mooney (1973) In patients whose feet have been deformed by operation, the alterations in weight distribution produced might predispose to the development of further lesions since the neuropathy is still present In patients who have had a ray amputation we have demonstrated heavy loads on areas of the foot which have gone on to develop recurrent lesions Such an alteration in loading is probably an inevitable sequel of ray amputations in which the toe and distal part of a metatarsal are removed, thus reducing the number of weight bearing metatarsal heads Transmetatarsal amputation (Wheelock 1961), which retains five weight-bearing metatarsal ends, might not have this disadvantage but we have not yet been able to test this

The lack of exact correspondence between the position of callosities and the measured position of maximum vertical load on the forefoot indicates that there could be other factors which are important in the development of callosities

The ability to identify the areas at risk for further ulceration gives information with which to plan preventative measures Adequate footwear and chiropody remain essential for the care of these patients Further studies are being carried out to test the effectiveness of splints designed to alter the loading on the foot These might delay the development of recurrent lesions and would represent an advance in therapy

## SUMMARY

Normal subjects and diabetic patients with and without foot ulcers have been studied using an apparatus which measures the loads on the foot during walking Diabetic patients have alterations in loading which show as a lateral shift of the highest maximum load on the forefoot and a decrease in the load carried by the toes There is a significant pro-

gression of these changes between normal subjects, diabetic patients with deformity of the foot but no ulcer, and diabetic patients with foot ulcers. All the patients with ulcers exerted maximum loads at the site of the ulcer.

## ACKNOWLEDGEMENTS

The authors wish to thank Professor L. P. Le Quesne and Dr J. D. N. Nabarro of the Middlesex Hospital, London, for permitting us to study patients in their care. The Polytechnic of Central London provided facilities for the work. Mr M. B. Undy of the Polytechnic gave considerable help with the statistical analysis of the results and Mr F. Graham did the drawings. This research is supported by a Medical Research Council grant. I.F. received a John Astor Fellowship of The Middlesex Hospital Medical School.

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*Key words* diabetes, neuropathic ulcers, foot, load distribution, callosities, walking

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Acta orthop scand 46, 848–856, 1975

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# CONGENITAL CLUBFOOT

## *A Follow-up of 95 Persons Treated in Sweden from 1940–1945 with Special Reference to their Social Adaption and Subjective Symptoms from the Foot*

TERJE BJONNESS

*Accepted 28 ii 75*

"*In assessing after-results in congenital clubfoot one must remember* that the patient is the final judge of whether he has a good foot, and there is quite a difference between theory and practice.

Occasionally one meets a patient whose foot by our standards is a thoroughly bad result and yet he is quite satisfied with it But isolated cases are no justification for allowing such deformities to occur or for failing to give the patient the best possible foot

Putting oneself into the patient's place, what would we want? We should want to be free from pain, to wear ordinary shoes, we should want to be able to play games or to dance, to earn a living or to look after a house and bring up a family" (Fripp 1951).

### MATERIAL AND METHODS

Between the 1st January, 1940 and the 31st December, 1944, 27,146 patients consulted the then existing institutions for the disabled in Goteborg and Helsingborg The journals have been gone through in order to see which persons were diagnosed as having congenital clubfeet during the above mentioned period Persons who in addition to congenital clubfoot suffered from arthrogryposis, cerebral palsy, or spina bifida were not included in the investigation as it was desired only to study those persons who could be considered physically fit except for their clubfoot/feet Persons born from 1939 to 1944 have been included Of those born in 1939 only those have been included who started treatment after the 1st January, 1940

106 persons with congenital clubfeet were found 82 men (77 4 per cent) and 24 women (22 6 per cent), 59 unilateral (55 7 per cent) and 47 bilateral (44 3 per cent) Ten individuals had died since the beginning of the treatment One person could not be traced

A questionnaire was sent to the remaining 95 persons The questions comprised

their subjective judgment of the feet and related social data. All questions were answered by all participants.

At the follow up, which was performed in the patients' homes, a clinical investigation of their feet was made. Ninety five persons were followed up, 93 of them by letter and by personal visit by the author in their homes. Two men were followed up by letter and by telephone. Both refused to allow a personal visit. They meant one had no pains of a subjective nature. The follow up thus comprised 99 per cent of the still living from the initial investigative material. (In certain cases where an objective estimation of the feet was necessary for the final conclusion, the follow up included [redacted] persons.) Of the 95 persons in the investigation, 74 were men and 21 women. In 51 cases the deformity was unilateral and in 44 bilateral. The average age at follow up was 30 years, the youngest person was 27 years of age and the oldest 33 years of age.

## RESULTS

A *hereditary history* could be established in 12 of the 95 patients (12.6 per cent).

*Associated abnormalities* could be found in five boys (5/95).

*The average age at the time of first treatment* was 4.2 months, 4.5 for unilateral and 3.7 months for bilateral.

### Treatment

Of 95 persons (139 feet) 82 were operated (121 feet), 42 had unilateral foot deformities and 40 bilateral. Fourteen persons (18 feet) were only treated through manipulative correction and plaster. (One person with a bilateral foot deformity was treated operatively on one foot and conservatively on the other.) On the 121 operated feet, 213 soft tissue operations and 104 skeletal operations were performed.

### Hospitalization and clinical check ups

Of the 95 persons, 87 had been treated during their stay in hospital and as out patients. The average number of days of hospitalization per person was 77. Those treated conservatively had an average hospital stay of 7 days. In eight cases treatment could be performed by clinical check ups only. The average number of out patient check ups was 16. The average age at the latest clinical check up was 12 years.

### Gymnastics at school

During their school years 27 persons were totally or partly exempted from gymnastics, 19 boys (24.3 per cent) and 8 girls (38.1 per cent). There was no statistically significant difference between the sexes in

regard to exemption from gymnastics. Of the 27 persons who were exempted from gymnastics 9 (17.6 per cent) had unilateral foot deformities and 18 (40.9 per cent) bilateral. Persons with bilateral club feet were exempted from gymnastics more frequently than those with unilateral club feet.

*Active athletics*

This aspect was investigated among 94 patients. Of 50 persons with unilateral club foot (37 men and 13 women), 18 men, but no women had participated in competitive sports (non-competitive sports were not included). Of 44 persons with bilateral club feet (36 men and 8 women), 10 men and one woman had actively competed in sports. Half of the men with unilateral foot deformities had taken part in competitive sports, while only 25 per cent of those with bilateral foot deformities had done so. Ball games were the dominant type of athletics.

*Military service*

Eight persons were exempted from or had reduced conscription for reasons other than their feet.

In the remaining 66 men full conscription was completed by 85 per cent of persons with unilateral foot deformities and by 57.5 per cent of those with bilateral club feet. Limited service or full exemption occurred in 15 per cent of those with unilateral foot deformities and in 42.5 per cent of those with bilateral deformities.

*Cosmetic problems*

At the follow-up, the patients and their relatives were questioned about cosmetic problems during childhood as well as those problems which remained at the time of the follow up. In 94 cases, these problems could be elucidated. Thirty-three persons stated that they had suffered from cosmetic problems during their childhood (31.5 per cent of the men and 47.6 per cent of the women). Of those 33 persons 14 stated that the problems remained at the time of the follow-up, 7 men (9.6 per cent) and 7 women (33.3 per cent). During childhood there was no significant difference between the cosmetic problems encountered by men and women. As regards their remaining cosmetic problems a statistically significant difference was noted at the 95 per cent level, at which the women more often voiced problems than the men.

*Civil status*

No statistical difference existed in the distribution of civil status among males and females when compared with the total population of corresponding age

None of the 21 women was divorced Two of the 74 men were divorced (2 7 per cent) This corresponded to the national average for the same age (3 per cent)

*Occupation*

All 95 persons had completed vocational training The occupation was mainly sedentary for 27 sedentary and walking for 58 standing and walking for 7 and composed of manual labour for 3

They were asked whether their feet had influenced their choice of occupation Eighty eight of the 95 persons had been able to manage their initially chosen occupation without difficulty In the case of four persons all of whom had subjective problems with their feet when they chose a vocation the community was obliged to provide rehabilitation aid Three of them function today without any problems in their new jobs while one carrying out an unplanned job at the time of follow up had the same subjective problems as before re training The remaining three persons have changed to other occupations on their own initiative and function in their daily working life without any foot problems

*Shoes*

Through the case histories the author has recorded the type of shoes at the time of the last clinical check up at the orthopaedic clinic i e the doctor's recommendation of shoes and possible changes Similar notations about shoes have been made at follow up examinations

*Table 1 Condition of shoes in 95 cases of congenital club foot*

| | Last check up | Follow up |
|---|---|---|
| Shop shoes | 16 | 77 |
| Shop shoes with insert | 33 | 9 |
| Shop shoes with modification of heels or soles | 26 | [illegible] |
| Orthopaedic shoe | 14 | 4 |
| Not yet walking | 4 | |
| No record | 2 | |

On the average, 18 years had elapsed between the previous check-up at the Orthopaedic Clinic and the follow-up examination During this time, the patients' shoe conditions had changed considerably Persons who used orthopaedic shoes had decreased from 14 of 89 (15 7 per cent) to 4 of 95 (4 2 per cent), while those who had their shoes altered by an orthopaedic workshop had decreased from 26 out of 89 (30 per cent) to 5 out of 95 (5 2 per cent). An insert had previously been used in "shop" shoes by 33 out of 89 (38 per cent) and at the follow-up was used by 9 out of 95 (9 5 per cent)

At the follow-ups, an abnormal increase in the wear and tear on the lateral side of the sole was observed in 2/3 of the 93 follow-up persons All follow-up persons indicated that laced shoes were best for their feet.

*The difference in the length of the feet* could be measured in 49 of the 51 persons with unilateral foot deformities The foot length was measured from the heel to the point of the big toe and the difference was between 0 5 and 7 cm—an average of 2 1 cm Four persons showed no difference in the length of their feet Fourteen of 16 persons with a difference in foot length of 3 cm or more used some sort of filling to compensate for the difference in foot length, e g inserts, paper, cotton and soles (In two cases the persons bought two pair of shoes of unequal size ) In cases of less than 3 cm difference in foot size similar alterations were made by 4 of 29 persons None of the persons with bilateral club feet had a foot length difference exceeding 3 cm and none used complementary insertions for compensation of their foot length difference

*The difference in the length of the legs* was measured with the patient in a standing position without shoes Roentgenologic measurement of the leg was not possible in this investigation In cases of pelvic tilt, a compensatory lumbar scoliosis existed which in all cases was soft and could be straightened out with heightening under the shorter leg Twenty-nine persons with unilateral foot deformities had a leg length difference of between 1 and 3 cm In three cases of bilateral club feet, a leg length difference of 1, 1 5 and 5 cm existed respectively

Only three persons compensated for leg length difference Two persons with unilateral foot deformities used corrective heightening of ½ cm each The shortening measured was 1½ and 2 cm respectively One person with a bilateral foot deformity and a leg length difference of 5 cm used corrective heightening insertions of 2½ cm

*Limping* Fifty persons with unilateral club feet were asked if they

considered themselves lame Thirteen persons answered more or less affirmatively In two of these, no measurable leg length difference existed Six persons had a difference of 1 2 cm and five a difference of 2–3 cm Since two persons without leg length difference indicated subjective limping and only 11 out of 29 with leg length difference of 1 3 cm thought likewise, there is reason to think that subjective limping is an expression of the individual's conception of the functions of leg and foot—independent of differences in leg length This might also partly explain why none of the persons with subjective limping had done anything to compensate their difference in leg length

*Functional foot symptoms*

On follow-up the following introductory questions were asked

1) "Can you walk on your foot/feet without problems?"

2) "Are your daily activities limited due to pains from your feet?"

Eighty eight persons mentioned that they had no symptoms, while foot problems occurred in seven (three females and four males), one unilaterally and six bilaterally This figure corresponds to 7 4 per cent of 95 follow-up persons

In order to get a closer look at the foot problems which occurred in these seven persons, some further questions were asked (see Table 2)

*Table 2 Functional foot symptoms in 7 persons with congenital club feet*

| | Number of persons |
|---|---|
| Pain in foot/feet | 5 |
| Tiredness in foot feet on walking | 0 |
| Difficulty in walking on a level surface | 2 |
| Difficulty in walking on uneven ground | 6 |
| Difficulty in climbing stairs | 2 |

Foot/feet pain occurred in five persons Four of these had daily pains which were provoked by wobbling movements in the ankle joint One person had daily pains in the big toe on which a partial phalangeal resection had been performed

Tiredness in the foot/feet did not occur in any of the cases

Difficulty in walking on a level surface was mentioned by two patients One of them had pain from the ankle joint of one of the sides which was fixed at 20 degrees of equinus He also had fixed subtalar

joints The other person had symptoms due to callosity on the big toe The condition was diagnosed as hallux flexus

Difficulty in walking on uneven ground was found in six patients In five of them, the difficulty was caused by a feeling of instability in the ankle joint In one case, pains occurred after a partial phalangeal resection due to a hallux/rigidus

Two persons with bilateral foot deformities had difficulty in climbing stairs Both of them had a fixed equinus deformity on one foot, of 20 and 30 degrees respectively, as well as fixed subtalar joints

The 88 persons who upon initial questioning mentioned that they did not have any foot problems which limited their daily activities were asked the same questions as were asked to the seven who had problems due to their foot deformity(ies) The result is shown in Table 3

*Table 3 Functional discomfort and/or difficulties in 88 persons who on preliminary questioning did not mention any problems due to congenital foot deformity(ies)*

| | Number of persons |
|---|---|
| Pain in the foot/feet | 3 |
| Tiredness in foot/feet on walking | 12 |
| Difficulty in walking on a level surface | – |
| Difficulty in walking on uneven ground | 7 |
| Difficulty in climbing stairs | 3 |

Foot/feet pain occurred in three persons and all of these had difficulties in walking on uneven ground The pain occurred in conjunction with wobbling movements in the ankle joint and disappeared after a few seconds

Foot/feet tiredness was experienced by 12 persons when walking and did not cause any pains (None of the seven persons with foot pains that limited their daily activities experienced tiredness in their feet This might be accounted for by the fact that they spared their feet and thus never reached their physical limit )

Difficulty in walking on a level surface was not evident

Seven persons had difficulties in walking on uneven ground, due to instability in the ankle joint

Three persons with bilateral club feet experienced difficulties in climbing stairs One man had both his feet fixed in an equinus position of 10 degrees and another had one foot fixed in an equinus position of 10 degrees One person experienced difficulties in climbing stairs in spite of a dorsiflexion of 15 degrees in both of his ankle joints

## DISCUSSION

In Anglo-Saxon and German literature there is a lack of complete information about the subjective attitude towards the foot in persons with club foot/feet Information about social adaptation is almost completely lacking

Of the feet followed up in this study 88 per cent (119/135) had an appearance which differed from that of the normal foot One fifth (19/95) of the persons had some discomfort such as pain tiredness or instability They all functioned well at work but seven were so troubled that it hampered their free time activities

Previous reports regarding the subjective functional results in patients with congenital club feet have mainly been focused on one or few subjective functional aspects (Peter 1952 Fredenhagen 1955 Wynne-Davies 1964 Nemechek 1968 Fjeldborg 1971)

The purpose of this study was to assess the functional capacity of people with club feet approximately 30 years after initiated treatment and to illustrate their adaptation to society in general with respect to their deformity With this in mind their period of schooling and also their present stage of maturity has been taken into account

During the interviews with the persons it was obvious that the dominant problem during their schooling and growing up period has been the cosmetic problems which have hampered their assimilation with the normal group e g during school gymnastics games and other sporting activities In spite of this a large percentage of them participated in active sports and even later in life several have taken part in competitive sports with good results Awareness of the foot s appearance has been an embarrassment for the majority in the group but in particular the men have been successful in overcoming this embarrassment and have shown good adaptability as for example in the case of military conscription with all its implications Military conscription obligations imply fairly heavy demands on the individuals concerned especially as regards walking and marching some of the persons were in fact assigned to lighter duties which they were able to fulfil The study also shows that the majority of the persons could fulfil the requirements of full time work in spite of considerable discomfort from the feet work was chosen to suit the *individual* s handicap but this does not imply that the individuals did not experience a meaningful role in their environment It is of interest to note that though some of the patients abstained from sports they still could undertake and

accomplish a full day's work. The fact that 95 per cent of the patients used ordinary standard shop shoes can be looked upon as an expression of relatively minor problems with their feet. With regard to marriage the present study group showed no significant deviation from the normal population in the same age group.

## SUMMARY

A follow-up, with special reference to social adaptation and subjective symptoms, was done on 95 persons with congenital club feet treated in Sweden 1940–1945. At an age of 27–33 years the individuals managed themselves well and in spite of physical as well as psychological handicap they deviated relatively only a little from the normal population as regards work, sports and other social adaptibility.

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*Key words:* congenital clubfoot, follow up, social adaption, subjective symptoms

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# CONGENITAL METATARSUS VARUS

## *On the Advantages of Early Treatment*

INGE REIMANN & H H WERNER

*Accepted 17 vi 75*

Metatarsus varus is a rather common foot deformity (Wynne Davies 1964) Even in non treated cases disabling deformities do not occur Disadvantages from cosmesis and foot wear can cause considerable problems but pain and impaired foot function are rare

It seems reasonable to apply the principle of early treatment to this condition as in other types of congenital foot deformities

The present study attempts to evaluate the need for treatment based on a clinical analysis

### MATERIALS AND METHODS

Over a 3 year period from 1967 1969 212 infants referred to the Orthopaedic Hospital in Copenhagen were diagnosed as having congenital metatarsus varus

Of the total number 159 (75 per cent) had bilateral foot deformities 103 (48 6 per cent) were girls and 109 (51 4 per cent) were boys Eleven patients had additional congenital deformities six had congenital club foot on the other side and five had calcaneo valgus foot

Treatment was administered to 84 (39 6 per cent) of the infants representing 148 39 9 per cent) of the feet (Table 1) The rest of the patients comprising 128 infants and 223 metatarsus varus deformities were all mild cases and thus only followed clinically until normal conditions were found

*Table 1 Material*

| | Number of cases | Number of feet |
|---|---|---|
| Treated earlier than 1 year of age | 68 | 117 |
| Treated later than 1 year of age | 16 | 31 |
| No treatment | 128 | 223 |
| Total | 212 | 371 |

accomplish a full day's work The fact that 95 per cent of the patients used ordinary standard "shop" shoes can be looked upon as an expression of relatively minor problems with their feet With regard to marriage the present study group showed no significant deviation from the normal population in the same age group

## SUMMARY

A follow-up, with special reference to social adaptation and subjective symptoms, was done on 95 persons with congenital club feet treated in Sweden 1940–1945 At an age of 27–33 years the individuals managed themselves well and in spite of physical as well as psychological handicap they deviated relatively only a little from the normal population as regards work, sports and other social adaptibility

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*Key words* congenital clubfoot follow up social adaption subjective symptoms

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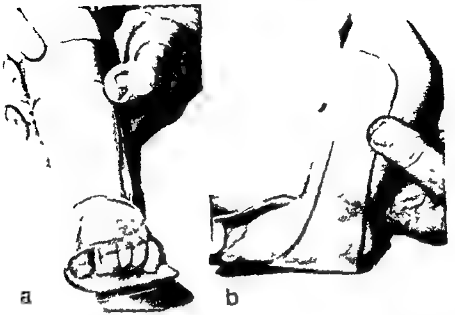


*Figure 2. The Plexidur® splint used in present material. a. Front view. b. Lateral view. The splint is kept fixed by an elastic bandage. At commencement of treatment the splint is adapted to a slight equinus and supination of the foot, and following correction the splint is adapted to neutral position.*

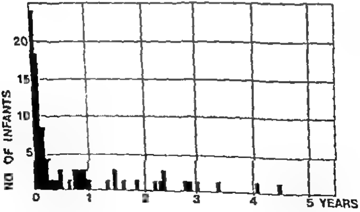


*Figure 3. Diagram showing the time for commencement of treatment. In 68 out of 84 treated cases the treatment was started at less than one year of age.*

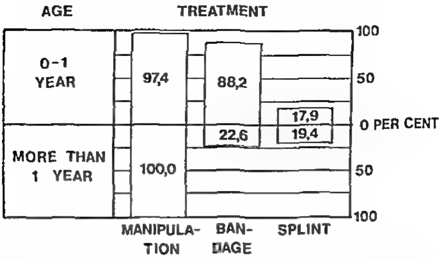


*Figure 1 Diagram showing the methods of treatment used in the present study*

The 84 treated cases all showed, at the onset of therapy, a typical deformity including adduction and inversion of the fore- and midfoot, a prominence at the lateral border of the foot, impaired plantar flexion and the great toe more separated from the second toe than normal (Figure 4 a) In most cases there was a slight increased valgus of the hindfoot

The methods of treatment are shown in Figure 1 In almost all of the cases manipulation was applied This treatment was initially given in an out patient ward by specially trained physiotherapists and later, after some weeks, carried out by the mother of the patient who had been properly instructed Elastic bandages were primarily used at less than one year of age *A combined treatment* including splinting was given in cases resisting several months of manipulation therapy In three cases, however, combined manipulation and splinting were started as early as within the first 3 weeks after birth For patients younger than one year of age a splint made of thermoplastic material was used (Figure 2), later a leather night splint was used

The commencement of treatment was as shown in Figure 3 The treatment was carried out for a period of 2–48 months All cases were seen regularly by the authors with intervals of weeks to months until the clinical results of the feet were satisfactory The average observation time was 22 9 months

The manipulation procedure carried out was as follows

First the decreased plantarflexion is treated especially the contracture of the anterior tibialis tendon The infant is placed in a supine position on the table with its feet towards the physiotherapist The ankle joint is fixed from behind by the heteronymous hand, with the thumb on the lateral and the index finger on the medial malleolus, and with the thenar the calcaneus is pressed in slight supination With the thumb of the homonymous hand placed across the dorsum of the foot proximal to the insertion of the tendon of the anterior tibialis the foot is pulled in plantar flexion

Correction of the adduction of the forefoot is the object of the next step The hindfoot is fixed from behind with the heteronymous hand with the thumb placed

treatment being combined with manipulations, complete correction was obtained after 1.5–2.5 months (Figure 4).

In the group treated at more than 1 year of age, satisfactory results were obtained in 15 of the 16 patients.

## DISCUSSION

Metatarsus varus was first described by Henke in 1863. Different terms such as pes adductus, metatarsus adductus and metatarsus varus are used (McCormick & Blount 1949), and it is still a point of discussion whether different types or degrees of severity occur.

In the present study 84 out of 212 infants showed pronounced adduction and inversion of the fore part of the foot at the time of first examination. Only in these patients with the typical appearance was indication for treatment found.

In addition to congenital club foot and vertical talus this type of metatarsus varus makes up a group of congenital foot deformities with no tendency to spontaneous recovery before weightbearing. Metatarsus varus, on the other hand, is the only deformity where correction after weightbearing can take place spontaneously.

These circumstances may be explained according to the nature of the deformity and are essential for the therapeutic principles as well as for the prognosis.

The lack of spontaneous recovery may be explained by the following reasons. The malposition at birth is caused not only by contractures in the soft tissues; subluxation in the fore- and midfoot and bone incongruity are also present (Reimann & Werner 1975). For this reason, the spontaneous muscle action is unable to overcome the resistance, as seen in calcaneo-valgus (Larsen et al. 1974).

Early conservative treatment such as manipulation or plaster cast will give good results in most cases (Kite 1950). Of 80 feet with marked metatarsus varus the results of conservative treatment were poor in only four cases (Ponseti & Becker 1966). This is in accordance with the present study.

In the three cases in which manipulative therapy was instituted together with adequate splinting during the first 3 weeks of life it was shown that complete correction was achieved within a few months.

Conservative treatment started at more than one year of age may be difficult because of resistant contractures as well as bony incongruity. Operative correction of these changes often leads to extensive capsul-


*Figure 4 Girl aged 12 days with bilateral metatarsus varus (a) Same case after 5 weeks of treatment with manipulations and Plexidur splint (b)*

on the lateral side of the calcaneus With the thumb of the homonymous hand placed at the medial side of the first metatarsal base and index and third fingers across the dorsum of the foot the forepart of the foot is pressed in abduction Simultaneously, calcaneus is pressed in slight supination by the heteronymous thumb

The object of the final procedure is stretching of the tissues on the medial side of the foot The ankle joint is fixed from behind with the homonymous hand With the thumb of the heteronymous hand placed at the level of the first metatarsal bone, traction along the medial border of the foot is carried out

## RESULTS

In the group where treatment was instituted before one year of age (68 infants with 117 metatarsus varus feet) satisfactory results were achieved in 65 of the infants Seventeen of the infants were seen for final examination before one year of age

For a satisfactory result i e feet with anatomically normal shape and without prominence at the lateral border of the foot the *functional* criteria are normal gait without increased adduction of the fore- and midfoot, but slight valgus of the heel allowed

In the 3 cases grouped as unsatisfactory, treatment was instituted at the age of ¾, 1½ and 4 months, respectively, and a splint was used from the age of 1, 4 and 5 months, respectively At the age of 2½, 4 and 5 years, respectively, a pronounced adduction of the fore- and midfoot combined with a prominence at the lateral border were present in all cases At reexamination 2 years later only slight adduction and prominence were seen, in spite of their having received no treatment during the two years prior to final observation

In the three cases treated with splint at less than 8 weeks of age, the

be explained by the influence of the position of the heel during weight-bearing

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*Key words* congenital metatarsus varus metatarsus varus foot deformities abnormalities

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otomies in the midfoot, and occasionally to osteotomies of the metatarsal bones (Heyman et al 1958)

Dwyer (1963) has shown, in club foot, that if the hindfoot is corrected to slight valgus the remaining part of the foot will gradually be normalized as a result of walking This spontaneous correction may take years

The slight valgus of the heel as seen in metatarsus varus may be responsible for spontaneous improvement during weightbearing, as opposed to the situation with club foot The fact that metatarsus varus is rarely seen in adults also points towards spontaneous correction

In the present study three cases not corrected at the age of 3 5 years showed spontaneous improvement during the following 2–3 years Operative correction should thus in most cases be kept in reserve

*Conclusions*

Early institution of conservative treatment with manipulations in most cases gives good results, but in combination with splinting it seems possible to reduce the period of treatment to a few months

It is difficult to estimate the effect of conservative treatment after weightbearing as spontaneous improvement may take place

Operative treatment is restricted to cases with severe contractures and bone incongruity

SUMMARY

Among 212 infants with congenital metatarsus varus 84 (39 6 per cent) of the infants were treated Only the treated group is considered in the analysis

Daily manipulative therapy was given followed by fixation in elastic bandage or splint The manipulations aimed at correcting the adduction of the fore part of the foot, as well as the increased valgus of the heel

In 68 infants treatment was instituted before one year of age The results were good in 65 of these patients and correspondingly good results were obtained in 15 out of 16 patients treated at more than one year of age

Subluxation in the fore and midfoot and bony incongruity present at birth are offered as a possible explanation for lack of spontaneous recovery before weightbearing as well as the occurrence of resistant cases

Spontaneous improvement may take place during childhood and may

## DYSPLASTIC HIP JOINTS TREATED WITH PAUWELS' VARUS OSTEOTOMY

*H Glastrup*

Reference is made to 61 operated hips on 52 patients All patients have been examined post-operatively

Pauwels' theory has been followed in treatment after revision of clinical and diagnostic criteria

Wrong diagnoses and treatment can be avoided and a lot of wrongly diagnosed patients can be helped to a painless or almost painless existence

## SUBTROCHANTERIC FRACTURES FOLLOWING NAIL OSTEOSYNTHESIS OF MEDIAL FRACTURES OF THE FEMORAL NECK

*A Bjorn Christensen & J S Kofod*

On the last 30 nail osteosyntheses performed at the Orthopedic Department, Frederiksberg Hospital, six subtrochanteric fractures have occurred through the hole made for the nail. Possible explanations are discussed. The secondary fractures were treated in one case with a Jewett nail in the rest with McLaughlin apparatus on the previous nail

## FEMORAL FRACTURES AFTER MOORE ARTHROPLASTY OR McLAUGHLIN OSTEOSYNTHESIS

*Borge Ruben Hansen*

The insertion of an inert surgical implant in living bone alters the biomechanical factors and induces stress concentration in the transmission zones Repeated loading of the system results in minute relative movements between the implant and the bone and may be the fundamental cause of a late fracture

A total of 36 patients with a hip prosthesis and 23 patients with a proximal internal fixation sustained a secondary fracture Most of the fractures were localized at or below the level of the shaft of the prosthesis or the McLaughlin plate, all were oblique fractures with considerable instability

In unstable fractures an internal fixation with a lateral eight hole plate has been considered the most convenient method secondary to a Moore arthroplasty In fractures secondary to a McLaughlin operation the original implant has been replaced with a long plate McLaughlin

## HYDROXYCHLOROQUINE SULPHATE IN PREVENTION OF DEEP VENOUS THROMBOSIS FOLLOWING HIP FRACTURES OR EQUIVALENT LESION

*Peter Østergaard F Hansen P Jessing H Lindewald & T Olesen*

A total of 153 patients with fracture of the hip or similar injuries were included in a double blind placebo controlled investigation of the usefulness of hydroxychloroquine sulphate [illegible]

The drug can reduce [illegible] this corresponds to th[illegible] [illegible] derivatives or dextran 70, but without the untoward side effects of these drugs

Acta orthop scand. 46, 864-868, 1975

# PROCEEDINGS OF THE

# DANISH ORTHOPEDIC SOCIETY

## 103rd ASSEMBLY

## KOLDING, DENMARK, MAY 2nd, 1975

### FEMORAL SHAFT FRACTURES: A COMPARISON BETWEEN MEDULLARY NAILING AND ASIF PLATE OSTEOSYNTHESIS

*J Steen Jensen, J. Johansen & A. Mørch*

In fractures of the middle third of the femur 60 medullary nailings (Kuntscher) and 49 ASIF plate osteosyntheses were performed The mortality rate was 7 8 per cent General complications were seen in 18 3 per cent—4 3 per cent being thromboembolic and 5 2 per cent fatty embolism Local complications were encountered in 26 8 per cent with an infection rate of 7 3 per cent. Seven cases of implant failure were described.

At the follow-up of 99 patients (average 3 5 years) the results were classified as excellent in 86 per cent The only differences between the two methods were concerning fracture healing and time of full weightbearing.

The results do not give grounds for unreasonable efforts in using medullary nailing instead of ASIF compression plates

### HAEMARTHRON GENUS

*Klaus Jacobsen & Erik Tøndevold*

All patients with knee haemarthrosis diagnosed by puncture in the casualty ward were, during a 5-month period, admitted to the Department of Orthopaedic Surgery

The primary diagnosis was based on conventional 2-plane radiography and clinical evaluation In the Department it was found that ⅔ of the patients with the primary diagnosis *haemarthron causa ignota* had major lesions in the knee joints

### DYSPLASTIC HIP JOINT PROBLEMS DISCUSSED THEORETICALLY

*H. Glastrup*

Pauwels' theories and calculations of the pressure on the hip joint are mentioned

Symptoms, diagnostic problems with other diseases, clinical and radiological findings are examined

Pauwels' varus osteotomy is a causal therapy to normalize the pressure per unit area

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Pauwels' theories and calculations of the pressure on the hip joint are mentioned. Symptoms, diagnostic problems with other diseases, clinical and radiological findings are examined.

Pauwels' varus osteotomy is a causal therapy to normalize the pressure per unit area.

## OSTEOARTHRITIS OF THE HIP TREATED WITH OSTEOTOMY

*Jens Evaldsen K Simesen & O Kallesøe*

An assessment has been made of 172 hips treated during the years 1964–73 in the Orthopedic Department, Kolding Merle D Aubigne s hip table was used for the assessment The effect on pain was best when pain was most pronounced Mobility was unchanged Without importance were the genesis, the duration of symptoms, the age of the patient and the technique of operation The effect lasted at least 7 10 years

## THE FIRST YEAR S EXPERIENCE WITH THE MONK PROSTHESIS

*Frank Wang Hansen*

At the Central County Hospital in Hillerød 66 Monk prostheses were used for total hip joint replacement in 1974

Hip assessments were made according to the method of Merle d Aubigne and the results found to be similar to the results obtained when using the Ring prosthesis The need for blood transfusions was on the average halved when using the Monk prosthesis

## DISCUSSION

*K Rechnagel*

In nearly 100 Monk operations using the southern approach we have seen no dislocations although the patients are allowed to lie freely in bed and start walking on the 10th day

To make the cup fit well we always reshape the acetabulum with a spherical mill

The stem is in many cases too short I should prefer a *long* stem coated with isoelastic material

## THE TREATMENT OF DIAPHYSEAL PSEUDARTHROSIS WITH A O COMPRESSION PLATE TECHNIQUE

*Kurt Simesen Joachim Boss Nielsen Erik Hammersjeld & Valther Mourit en*

The A O compression plate technique was used in 22 cases of diaphyseal pseudarthrosis The average pseudarthrosis time was 13 months

All the pseudarthroses united Average healing time was 4 months

*Complications* One infection one refracture four skin necroses

*Conclusion* The method is very suitable, with high probability of healing, tolerable frequency of complications and rapid rehabilitation

## A METHOD OF MEASURING THE ABILITY TO BEAR WEIGHT IN PATIENTS OPERATED FOR FRACTURE OF THE FEMORAL NECK BY APPLYING EARLY WEIGHTBEARING

*Arne Skipper*

The results are presented here of a 2 year examination concerning the ability to bear weight in all patients with fracture of the femoral neck operated upon in the Department of Orthopaedic Surgery, Odense Hospital

## AN UNDISPLACED EXPERIMENTAL FRACTURE IN RATS

*Jørgen Greiff*

A total of 42 inbred hooded rats of an average weight of 250 g sustained a fracture of the tibia. Prior to the fracture a medullary nailing was carried out with a 0.7 mm stainless steel wire. 43/44 fractures were transversal; 6/44 nails bent more than 5 degrees. Radiologic union occurred within 3–4 weeks.

## AUTORADIOGRAPHIC STUDIES OF THE COURSE OF HEALING OF RAT TIBIA FRACTURES USING 99mTc-Sn-POLYPHOSPHATE

*Jørgen Greiff*

Using 99mTc-Sn-Polyphosphate, 34 inbred hooded rats (average weight 245 g) had macroautoradiograms made of medullary nailed tibia fractures, 1–10 weeks after the trauma. The increased radioactivity was located in the callus, epiphyseal growth plate and from the 5th week in smaller areas in the cortical bone.

## MICROAUTORADIOGRAPHIC LOCALISATION OF 99mTc-Sn-POLYPHOSPHATE IN RAT CALLUS

*Jørgen Greiff*

Six inbred hooded rats with an average weight of 293 g and a 2 week-old medullary nailed tibial fracture supplied callus for the microautoradiographic study. The 99mTc proved to be diffusely scattered solely within the mineralised part of the callus.

## THE TARSAL TUNNEL SYNDROME (ELECTRODIAGNOSTICS)

*S. Pilgaard & A. Oster*

The tarsal tunnel syndrome is a nerve compression syndrome. Its aetiology, symptoms, signs, differential diagnosis and treatment are reviewed. The value of the evaluation of the motoric distal latency and the motoric conduction velocity time in the posterior tibial nerve is pointed out, the differential diagnostic value of these criteria being stressed. The authors find that the value of the electrodiagnostic procedures in tarsal tunnel syndrome is greater than that of electrodiagnostic examination in carpal tunnel syndrome (Pilgaard, S.: *Nord. Med.* 81, 131, 1969).

## TRANSVERSAL OR SAGITTAL TECHNIQUE IN LOWER LEG AMPUTATION FOLLOWING ARTERIOSCLEROTIC GANGRENE

*Niels B. Termansen*

In a prospective, randomized investigation including 88 patients with arteriosclerotic gangrene two techniques of below knee amputation were compared (sagittal technique (Persson & Sunden 1971) and transversal technique (Ghormley 1946)).

Reamputation above the knee was more frequent after sagittal than after transversal amputation. The difference was not statistically significant. Otherwise no differences in the results were found (primary healing, fitting of prosthesis, ambulatory and social status).

*References:* Ghormley (1946). Persson & Sunden (1971).

Acta orthop scand 46 869-876 1975

Department of Orthopaedic Surgery and Department of Pathology
University of Umeå Umeå Sweden

# PRIMARY LIPOSARCOMA OF BONE

SVEN ERIK LARSSON RONNY LORENTZON & LENNART BOQUIST

*Accepted* [redacted] *ii 75*

Liposarcoma is not uncommon among soft tissue sarcomas comprising approximately 8 per cent according to a recent report (the Swedish Cancer Registry Incidence Report 1971) In contrast liposarcomas primarily arising in bone are extremely uncommon despite the fact that the bone marrow is rich in adipose tissue Catto & Stevens (1963) reviewed the world literature and could find only 15 cases which were interpreted as primary liposarcoma of bone Only one case, that reported by *Dawson* (1955), was considered completely convincing To this can be added reports by Honore et al (1963), Goldman (1964) and *Mastragostino* (1965)

The following case is presented because of the rarity of this neoplasm and because it is still a matter of debate whether or not this lesion represents a clinically well defined entity The finding at primary surgical intervention of a tumour located entirely within bone with no other primary locus and which consisted of undifferentiated lipoblasts indicates that this case represents a genuine primary liposarcoma of bone

## CASE REPORT

*Clinical roentgenological and operative findings*

A 45 year old female was admitted on January 17 1958 because of nausea subfebrility and a weight loss of 8 pounds during the previous 4 months She complained of steadily increasing pain in the region of the proximal left femur and had a left sided limp

Physical examination on admission was normal except for pain on application of local pressure on the major trochanter of the left femur Motion of the hip joints was normal and Lasègue's sign was negative No tumours were noted on careful examination of the thigh and hip region or elsewhere and there was no lymphadenopathy Routine laboratory examinations of blood and urine were normal

Roentgenograms of the left hip showed an osteolytic lesion of approximately

The study involved 40 patients, 21 with medial fractures, and 19 with pertrochanteric fractures The ability to bear weight was measured thus

The patient stood with the operated leg on bathroom scales and the contralateral leg on a fitted stool The weightbearing was then converted into a percentage of the bodyweight, and a curve was drawn on a graph to show the amount of weight borne by each patient

The material clearly shows that none of the patients put all their bodyweight on the operated leg from the start, but that the ability to bear weight increased gradually from a few days after osteosynthesis and that this ability increased more rapidly in patients with medial fractures

whatsoever On histopathological examination of the curetted specimen no definite diagnosis was reached but lipoidosis and osteomyelitis were considered

Postoperatively, the patient had progressively increasing severe pain from the region of the lesion and roentgenograms of the left hip showed local progression of the osteolytic destruction Roentgenograms of the lumbar spine sacrum pelvis and skull were normal

On February 8 another operation was performed with curettage of the lesion Bacterial cultures on tissue specimens from the lesion and on blood samples were negative On histopathological examination, the diagnosis of liposarcoma primarily arising in bone was made

On February 15 roentgenograms of the left hip showed a spontaneous fracture through the major trochanter (Figure 1) which had occurred despite treatment in tibial traction Radiotherapy was instituted and over a period of 25 days a total dose of 4 500 rad was given towards the ventral region of the left hip In spite of this treatment roentgenograms showed a further progression of the lesion and no healing of the fracture The patient s condition went steadily downhill the neoplastic tissue showed growth through the operation wound and spread of the tumour occurred to the left iliac fossa On June 2? 1958 approximately 5 months after the first admission the patient died in pulmonary insufficiency because of widespread metastases in the lungs

## Necropsy

At post mortem examination tumour tissue was seen to bulge up through the wound in the left trochanter region The proximal left thigh was completely infiltrated by a necrotic tumour that had invaded the muscles and subcutaneous tissues The whole proximal part of the femur was completely destroyed by the tumour The left ilium was intact Grossly the tumour was greyish white and had a partly soft partly more firm fibrous consistency Within the tumour mass only a few small bone fragments remained of the destroyed proximal femur

The lungs exhibited miliary metastases and oedema The liver and the left kidney contained several metastases of varying size There were also metastases in the retroperitoneal lymph nodes All the other visceral organs were carefully examined and found to be normal

## Microscopic findings

Histopathological specimens taken at biopsies and at post mortem examination were re-examined and additional slides were made at the time of re-examination of the cases The following stains were used Haematoxylin eosin van Gieson s stain Sudan black B periodic acid Schiff (PAS) Laidlaw s silver impregnation and phosphotungstic acid haematoxylin (PTAH)

On review of the sections the diagnosis of liposarcoma of the bone could be substantiated The primary tumour in bone exhibited considerable polymorphism (Figure 2) It consisted mainly of large cells with vacuolated and empty looking cytoplasm (Figure 3) with an admixture of small round cells The nuclei of the large tumour cells were irregular often hyperchromatic and of varying size (Figure 4) In some nuclei enlarged nucleoli could be discerned The cell membranes were distinct Many large tumour cells were rounded others were irregular They were

*Figure 1 Roentgenogram of the proximal left femur taken 29 days after admission demonstrating a very rapid progress of osteolytic destructive changes within the proximal femur with a spontaneous intertrochanteric fracture*

2 inches in diameter in the major trochanter of the femur The destruction was located entirely within the bone with disappearance of spongious bone and some erosion of the adjacent cortical bone Roentgenograms of the lungs stomach and duodenal bulb were normal

At surgical biopsy of the lesion the cortex of the major trochanter was found to be completely intact After fenestrating the cortical bone a relatively small soft lesion was found located entirely within bone with no extraosseous component

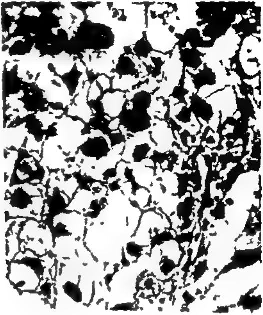


*Figure 4 Another portion of the liposarcoma demonstrating tumour cells with irregular, hyperchromatic nuclei an empty looking cytoplasm and distinct cell boundaries Haematoxylin & Eosin × 100*

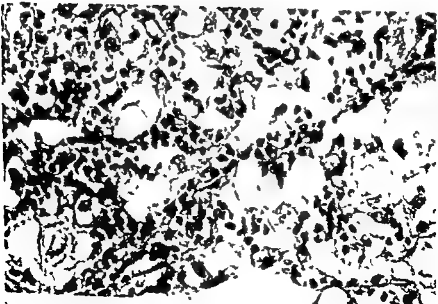


*Figure Another view of the liposarcoma showing a mitotic figure in a large tumour cell (lower left corner) and streaks of small round cells Haematoxylin & Eosin × 50*

*Figure 2 Photomicrograph of a primary liposarcoma of the bone showing polymorphism of the tumour cells and portion of a bone trabecula Haematoxylin & Eosin × 80*

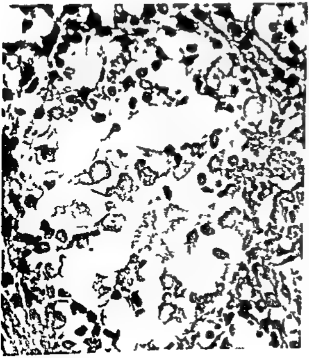
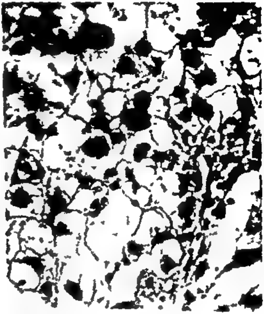


*Figure 3 Liposarcoma of the bone showing large tumour cells with vacuolated cytoplasm and small round cells Haematoxylin & Eosin × 100*



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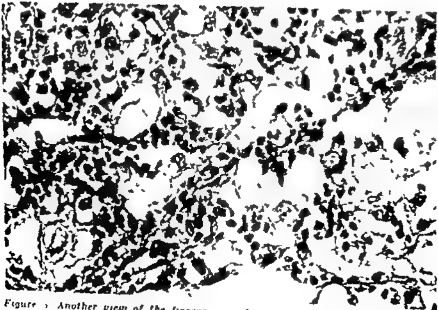

*Figure 5 Another view of the liposarcoma showing a mitotic figure in a large tumour cell (lower left corner) and streaks of small round cells Haematoxylin & Eosin × 80*

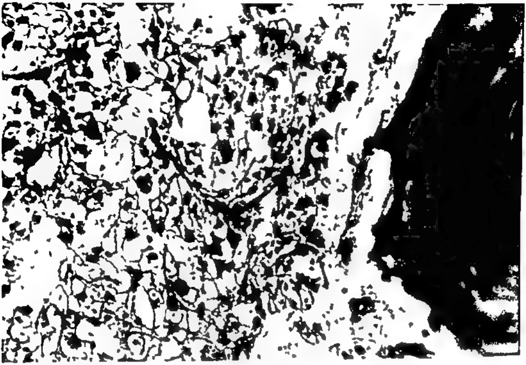

*Figure 2 Photomicrograph of a primary liposarcoma of the bone showing polymorphism of the tumour cells and portion of a bone trabecula Haematoxylin & Eosin, × [illegible]*

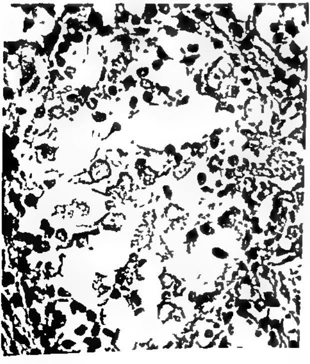

*Figure 3 Liposarcoma of the bone showing large tumour cells with vacuolated cytoplasm and small round cells Haematoxylin & Eosin, × 100*

sarcoma of the bone This patient was a 30 year old man with a lesion of the proximal end of the fibula which was resected Histopathological examination showed a liposarcoma of mixed cell type The patient was still alive after 4 years with no evidence of recurrence As in our case there was severe local pain at the onset of tumour growth Another case was convincingly reported by Catto & Stevens (1963) This patient was a 16 year old girl with a tumour of the upper end of the tibia with the microscopical appearance of a liposarcoma of mixed cell type Despite mid thigh amputation this patient died 9 months after admission with pulmonary and liver metastases Honore et al (1963) reported on a 36 year old female with a liposarcoma of mixed cell type in the distal femur causing severe pain The patient was alive with no signs of any metastases at the time of the report i e 17 months after the onset of the first symptoms and 10 months after surgical treatment (exarticulation at the hip joint) had been instituted Goldman (1964) reported a case of a liposarcoma of mixed cell type with primary localization to the mid portion of the ulna in a 33 year old man This patient was alive without any evidence of metastases 3½ years after a supracondylar amputation of the humerus Severe local pains over the tumour were noted in this patient also Except for these reports of convincingly described cases there are reports of probable but not proven cases which are summarized in the reviews by Catto & Stevens (1963) and Schwartz et al (1970) In addition two cases of primary bone tumours composed of both lipoblastic and osteogenic neoplastic tissue were described by Schajowicz et al (1966) and Ross & Hadfield (1968) Although there seem to be rare cases of primary bone tumours of two different types of mesenchymatic origin our case obviously represents a genuine primary liposarcoma of the bone

Microscopically the cases of primary liposarcoma referred to above were of mixed cell type presenting a marked polymorphism Both clinically and histopathologically these tumours showed all the characteristics of a sarcomatous neoplasm with a high potential of malignancy Radical resection when feasible or amputation in cases with more peripheral localization is to be recommended as well as irradiation treatment Although rare this neoplasm appears to constitute a clinically well defined entity Examining all cases of this tumour recorded by the Swedish Cancer Registry between the years 1958 1968 we have been unable to find another case with a proven diagnosis other than the one presented here

strongly positive for fat Mitotic figures, occasionally of atypical appearance were seen among the tumour cells

The general growth pattern of the tumour cells was that of solid sheets with no tendency to acinar arrangement or spinocellular differentiation A moderately developed and moderately vascularized stroma of connective tissue was observed Regressive changes, frank necroses and bleedings were seen in the tumour tissue

The masses of tumour cells infiltrated the areas between the bone trabeculae The latter were occasionally more or less destroyed and sometimes the bone seemed to have completely disintegrated The microscopic appearance of the metastases in liver, left kidney, lungs and lymph nodes showed a similar picture

The histopathological details of the liposarcoma of the bone did not seem to deviate from those seen in liposarcoma primarily localized in the soft tissues

## DISCUSSION

The above-mentioned liposarcoma was obviously primarily localized in bone There was no evidence of overgrowth on bone of any liposarcoma arising in the adjacent soft tissues, which can occur in rare instances (Ressel et al 1966) This was evidenced by X-ray examinations and thorough surgical exploration Histopathologically, the tumour was strongly positive for fat and was composed of large cells with vacuolated cytoplasm and irregular, hyperchromatic nuclei of varying size and also of small round cells Because of the variation in the histopathological appearance of these tumours there can be difficulties in the differential diagnosis especially towards other sarcomatous tumours of myxoid, lipomatous and fibrous appearance In the present case of a primary bone tumour, the microscopic picture was that of a polymorphous liposarcoma corresponding to the mixed category described by Stout (1944) Malignancy was indicated by infiltrative growth and the appearance of metastases

Clinically, the tumour exhibited a very malignant course Despite curettage and combined irradiation treatment at a total dose of 4,500 rad, the tumour showed rapid invasive growth with destruction of bone, spread to the iliac fossa and penetration through the operation wound Approximately 5 months after admission the patient succumbed due to widespread metastases in the lungs, liver and left kidney

The clinical course in our case corresponds well to that of the patient described by Dawson (1955) This patient was a 28-year old female with a liposarcoma of mixed cell type in the femur who, despite amputation by disarticulation at the hip joint died 9 months later due to metastases in the left lung and spine The first of the two cases reported by Mastragostino (1965) appears also to be a primary lipo-

sarcoma of the bone This patient was a 30-year-old man with a lesion of the proximal end of the fibula which was resected Histopathological examination showed a liposarcoma of mixed cell type The patient was still alive after 4 years, with no evidence of recurrence As in our case there was severe local pain at the onset of tumour growth Another case was convincingly reported by Catto & Stevens (1963) This patient was a 16 year-old girl with a tumour of the upper end of the tibia with the microscopical appearance of a liposarcoma of mixed cell type Despite mid thigh amputation this patient died 9 months after admission, with pulmonary and liver metastases Honore et al (1963) reported on a 36 year-old female with a liposarcoma of mixed cell type in the distal femur causing severe pain The patient was alive with no signs of any metastases at the time of the report, i e 17 months after the onset of the first symptoms and 10 months after surgical treatment (exarticulation at the hip joint) had been instituted Goldman (1964) reported a case of a liposarcoma of mixed cell type with primary localization to the mid portion of the ulna in a 33-year old man This patient was alive without any evidence of metastases 3½ years after a supracondylar amputation of the humerus Severe local pains over the tumour were noted in this patient also Except for these reports of convincingly described cases there are reports of probable but not proven cases which are summarized in the reviews by Catto & Stevens (1963) and Schwartz et al (1970) In addition, two cases of primary bone tumours composed of both lipoblastic and osteogenic neoplastic tissue were described by Schajowicz et al (1966) and Ross & Hadfield (1968) Although there seem to be rare cases of primary bone tumours of two different types of mesenchymatic origin, our case obviously represents a genuine primary liposarcoma of the bone

Microscopically, the cases of primary liposarcoma referred to above were of mixed cell type presenting a marked polymorphism Both clinically and histopathologically these tumours showed all the characteristics of a sarcomatous neoplasm with a high potential of malignancy Radical resection when feasible, or amputation in cases with more peripheral localization, is to be recommended as well as irradiation treatment Although rare, this neoplasm appears to constitute a clinically well defined entity Examining all cases of this tumour recorded by the Swedish Cancer Registry between the years 1958–1968 we have been unable to find another case with a proven diagnosis other than the one presented here

## SUMMARY

A case is presented of a rare primary liposarcoma of bone localized to the major trochanter of the left femur of a 52-year-old female Despite combined treatment with curettage and irradiation with a total dose of 4,500 rad the neoplasm showed rapid invasive growth with destruction of the bone, spread to the iliac fossa and outgrowth through the operation wound Approximately 5 months after admission the patient succumbed due to widespread metastases in the lungs, liver and left kidney The histopathology, clinical course and treatment of this rare neoplasm of the bone are discussed

## ACKNOWLEDGEMENT

This work was supported by grant no 711 B74 02X from the Swedish Cancer Society

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*Key words* bone neoplasm liposarcoma

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# CLINICAL ASSESSMENT OF GAIT USING LOAD MEASURING FOOTWEAR

P HARGREAVES & JOHN T SCALES

Accepted 7 iii 75

There is a need in orthopaedic surgery for objective measurements to augment the subjective observations of the clinical state of patients who have had weightbearing bone and joint replacements For this reason, the load measuring footwear programme was initiated The system enables information to be obtained about the foot floor load relationship with the patient at rest and in motion In particular, it was hoped that units of measurement could be used in assessing the patient s clinical progress

Various techniques such as chrono photography (Marey 1885), cinephotography (Muybridge 1887), or the use of accelerometers (Liberson 1936) have been used to monitor the gait Another technique, more suitable for use in clinical practice, is the measurement of the forces acting between the foot and the floor The forces can be measured by devices set in the floor (Cunningham & Brown 1952), or by devices fitted to the foot (Holden & Muncey 1953, Marsh 1953) Floor mounted force plates can be portable but their position imposes restraints on the walking pattern of the patient A walk has to be paced to produce the single step measurement which is in itself a limitation A more useful number of footsteps can be observed using a pair of longer force plates (Skorecki 1966) Care is necessary to keep the feet on the appropriate plates and difficulties also arise when people use walking aids These are not portable and constructional factors usually result in these systems being costly

The alternative method of measuring the forces transmitted through the feet to the floor is to attach the measuring devices to the patient's feet Provided care is taken with the design of the devices and their

incorporation into footwear, this method is less disruptive to the patient's walking pattern A system of this type designed without trailing leads would be free of restrictions to particular walk paths and the psychological influence would be reduced An advantage of the system is that it can be extended to include monitoring of the forces transmitted through walking aids

Any system for use in a clinic must

1) impose the minimum restraint on the normal gait activity of the patient,
2) be reliable,
3) be simple to operate,
4) be suitable for commercial production,
5) be relatively cheap and
6) produce records which can be easily interpreted

Because of these requirements it was decided that the load measuring footwear should measure only the dominant vertical component of the forces acting between the foot and the floor In addition, the device should respond equally to load over the full area of the foot and not differentiate between different areas of the foot, thus avoiding the complications of multi-trace presentations

## EQUIPMENT AND METHODS

The basic equipment for clinical use consists of instrumented footwear, the receiver unit a calibration device and some form of recorder The laboratory and clinical trials were carried out using a prototype receiver and one size of sandal of an open construction which were produced by the Royal Aircraft Establishment, Farnborough These prototypes were designed around a sandwich transducer and incorporated a transmitter and battery unit in the heel There were problems in fitting these sandals to differently proportioned feet even within the limited range of length fittings The lack of balance of the sandal and the flat sole were additional factors which were liable to influence the gait pattern The design of footwear has been developed as a result of the clinical trials A modified sports shoe (Figure 1) is used with the transducer replacing the loose insole The transmitter and battery packs which are housed in pockets on the side of the shoe could alternatively be carried on a belt The flexible canvas uppers and the lacing down to the toes facilitates the fitting of the shoes to misshapen feet and to feet of differing proportions The sole of the sports shoe is contoured in two directions giving a rocker feature which is a factor in the design of normal footwear

A length of wire placed on the floor around the walkway area acts as the aerial for the receiver The main functions of the receiver are to separate the electrical

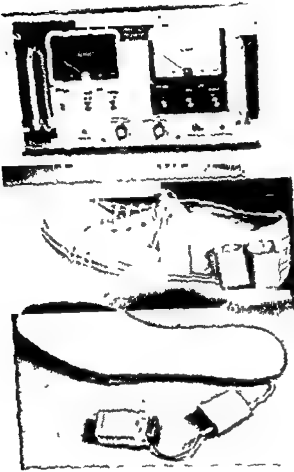


*Figure 1 Current design of receiver and footwear*

signals received from the two transmitters and to process these signals to make them suitable for display and recording The latest design of receiver, shown in Figure 1 incorporates facilities for calibration of the display

The diagram (Figure 2) sets out the basic details of the recordings The upper trace is the left foot recording and the lower trace the right foot recording Load as a percentage of body weight is graphed vertically against time (Note the horizontal measurement does not represent length of stride ) The swing phase relates to the portion of the cycle when the foot is not touching the ground and no load is transmitted The stance phase is when the foot is on the ground and a force is transmitted The two load peaks are sometimes designated "heel and toe" This can be incorrect and more generally applicable terms are depicted on the lower

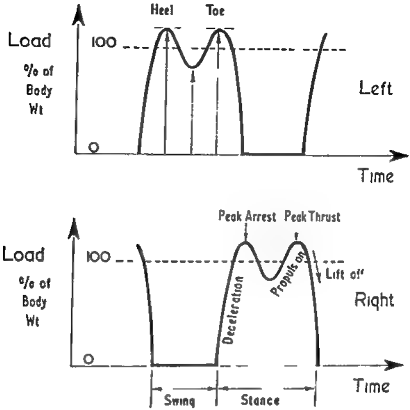



*Figure 2 Nomenclature*

trace namely peak arrest and peak thrust Additional terms relating to the gait cycle deceleration propulsion and lift off are shown on the relevant sections of the trace

*Normal gait control trials*

A series of recordings was made of people with reasonably normal gait characteristics The criterion of normal gait was that the left and right actions should be similar and that there should be no marked variations in the walk pattern over a period of time This series proved the consistency of the recordings the reliability of the system and established the operating procedures

*Comparison with other methods*

The patterns obtained from the load measuring footwear have been compared with published work—for example from the University of California Berkeley (1947) and from the Building Research Station Garston (Harper et al 1961) with recordings produced by the Charnley and Rydell walkways and directly using a Kistler force platform All the recordings show substantially the same characteristics

*Patient recordings*

Patient trials were undertaken to obtain information about the following

1) the acceptability of the system by the patients
2) the establishment of the operating procedures
3) the determination of the significant factors of the traces

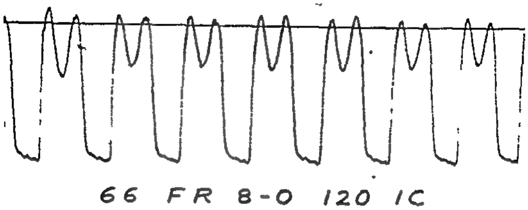
The sandals were fitted to the patient who was then allowed to walk around to become accustomed to the feel of the sandals The patient was then asked to walk at a comfortable speed The step rate was timed and this value was used for the setting of an electronic metronome Recordings were then made with the patient walking with or without sticks or crutches dependent upon his walking ability When a recording was made at the time when use of a walking aid had just been discontinued a recording was made still using the aid to give a continuity of information at the changeover point When recording after an operation the same procedures were used to determine the comfortable walking rate On subsequent occasions recordings were made at this rate—if there had been no deterioration in the cond tion of the patient—and at the new increased comfortable rate Thus comparisons were made at two rates one fixed and the other at an increasing rate a changing value but comparable through being the fastest comfortable rate at any particular time On occasions recordings of the gait were made when the patient thought that the observations had been concluded There were no significant dif ferences in the quality or quantity of the gait

Recordings were made of the gait of 16 patients (11 male and 5 female) In eight of these cases (including one bilateral) recordings were taken before and after total hip replacement A total of 410 recordings of the gait of these patients have been made over a period of 3 years From these records some 8000 steps have been stud ed A selection of these recordings from the patients listed in Table 1 has

*Table 1*

| Case | Sex | Age | Occupation | Condition | Gait feature |
|---|---|---|---|---|---|
| 1 | M | 39 | Charge Nurse | Osteoclastoma (R) femur | Long term observation |
| 2 | F | 64 | Housewife | O A L and R hips | Use of sticks and crutches |
| 3 | M | 40 | Mechanical Engineer | Radionecrosis (L) head and neck of femur | Stair climbing |
| 4 | M | 55 | Farmer | O A (L) hip | First walk after operation |
| 5 | M | 63 | Retired | O.A | Value of stick |

O A Osteoarthritis



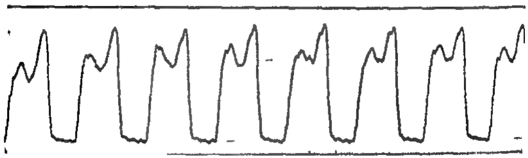



*Figure 3 Gait recording 3 (Case 1) 5 weeks after operation, Cadence 80, 2 crutches*

been made to illustrate the changes in gait which related to various clinical features

## FINDINGS

### *Case 1—Long-term observation*

The first gait recording (Figure 3) was made five weeks after the replacement of an upper third right femoral prosthesis in which the intramedullary stem had fractured The maximum comfortable cadence, using two crutches, was approximately 80 steps per minute Only 50 per cent load was taken on the right foot and showed that the patient was controlling the deceleration phase and protecting the heel strike Three weeks later the patient was at the stage where he could walk at 120 steps per minute using one crutch held in the left hand (Figure 4) The load on the left foot had increased and the peaks were more rounded The load taken on the right foot had also increased Subsequent to the controlled action of the deceleration phase it showed

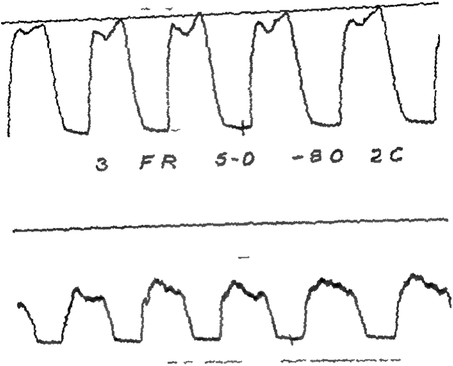



*Figure 4 Gait recording 66 (Case 2) 8 weeks after operation Cadence 1[illegible] 1 crutch*

the greater ability of the limb to sustain or generate an increased thrust off load The overall pattern of loading was now more normal Further recordings were made 14 weeks after operation when the patient was able to walk unaided at a cadence of 120 (*Figure 5*) The overall pattern was smoother and showed a slight increase of heel and toe loads on the right foot The left foot pattern had a deeper trough which was a result of a more vigorous uninhibited gait action The patient's new standard gait at 120 unaided 45 weeks after operation is illustrated in Figure 6 The pattern of the right foot loading had improved still further in that there was increased amplitude of the first peak illustrating a less restrained action at heel strike

### Conclusions

This series of recordings has shown the progression of the patient over the period of time up to the attainment of his new normal gait

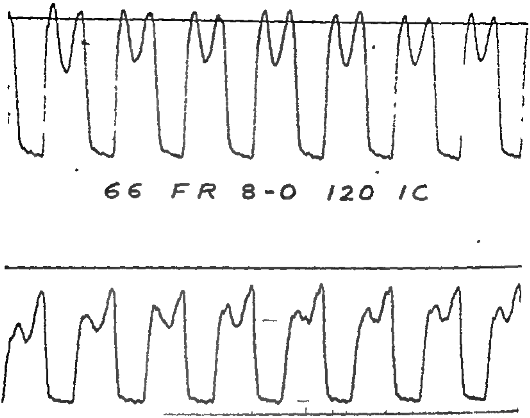



*Figure 3 Gait recording 3 (Case 1) 5 weeks after operation, Cadence 80, 2 crutches*

been made to illustrate the changes in gait which related to various clinical features

FINDINGS

### *Case 1—Long-term observation*

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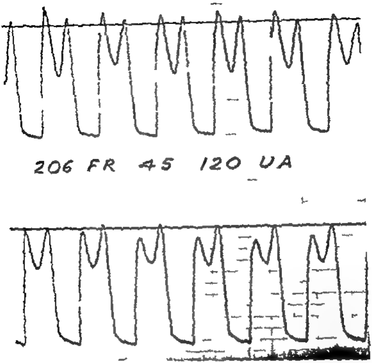


Figure 6 Gait recording 206 (Case 1) 45 weeks after operation Cadence 120 unaided

as proficient in the use of one stick Figures 8 and 9 indicate that the patient required the use of two sticks

Two additional recordings were taken 3 weeks after operation of walking at the slow cadence measured after operation—45 per minute—and using two sticks in two ways in phase (Figure 10) and alternating (Figure 11) When the sticks were used in phase there was an irregular loading However when the patient walked using the sticks in the alternating mode the loading pattern was much smoother These recordings illustrated the patient's difficulty in walking with sticks in phase—the recommended method The patient preferred to use the sticks in the alternating mode

*Conclusion*

The recording enabled

1) an assessment to be made of the value using two sticks compared with one stick

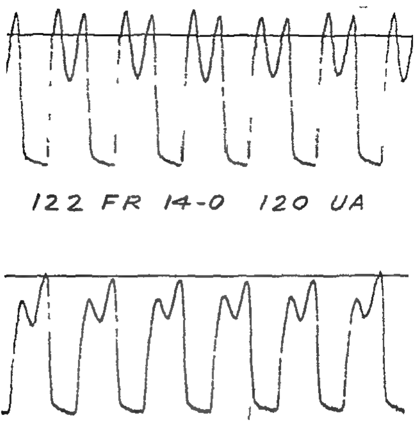


*Figure 5 Gait recording 122 (Case 1) 14 weeks after operation, Cadence 120 unaided*

*Case 2—Use of sticks and crutches*

Two weeks and 4 days after operation for a right total hip replacement (Ring), using two crutches at a low cadence, the waveforms were irregular, with only 40 per cent of the body weight being taken on the right foot (Figure 7)

Only 2 days later a marked improvement in the pattern of the gait was observed (Figure 8) The pattern was smoother, the peaks had appeared and the cadence had increased to 80 This improvement was coincident with a change from using crutches to using two sticks With one stick (Figure 9) there was an increase in the peak amplitude of the left foot loading, compared with the values recorded in Figure 8 Comparing Figure 9 (1 stick) with Figure 8 (2 sticks) the patterns of the left and right gait were not as smooth and there was an increased irregular load observed on the left with a sharp thrust peak on the right This is similar to a pre operative observation that the patient was not

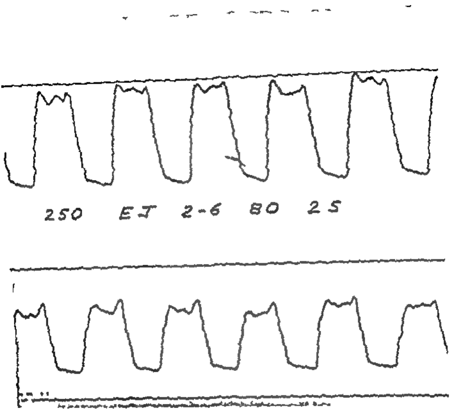


*Figure 8 Gait recording 250 (Case 2) 2 weeks and 6 days after operation Cadence 80 2 sticks*

load sustained by the feet i e a higher rate of deceleration *There was* about *80* per cent of the body weight load transmitted through the left foot *on descent and 85* per cent on ascent On the right foot a double peak curve was produced by a gait which was ball of foot only, not heel *and toe on both ascent and descent*

*Conclusion*

1) The waveform developed during walking does not indicate the sequential pattern of application of load to the foot, normally heel and *toe*
2) In climbing stairs the peak thrust exceeds the peak arrest, *while* in descent the *peak* arrest is greater

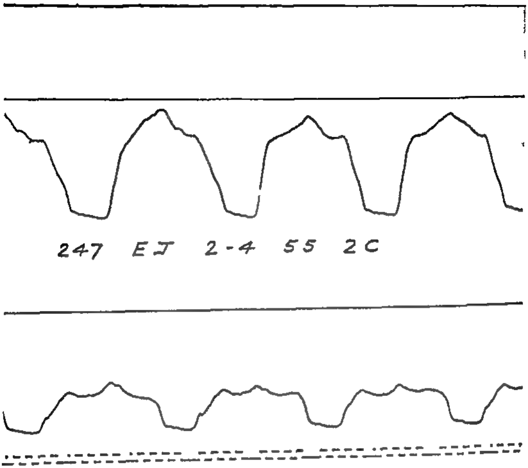


*Figure 7 Gait recording 247 (Case 2) 2 weeks and 4 days after operation, Cadence 55 2 crutches*

2) an assessment to be made of the value of crutches compared with sticks,
3) an assessment to be made of the value of the mode of use of walking aids

*Case 3—Stair climbing*

Figure 12 shows a gait recording of the patient, 2 years after operation for replacement of the upper femur, climbing up and down stairs, without a walking aid, but using a handrail In ascending the stairs there was a slower rate of rise of load in the deceleration phases of both the left and right foot loads since the person was raising the body weight In descending the stairs, there was a rapid development of the

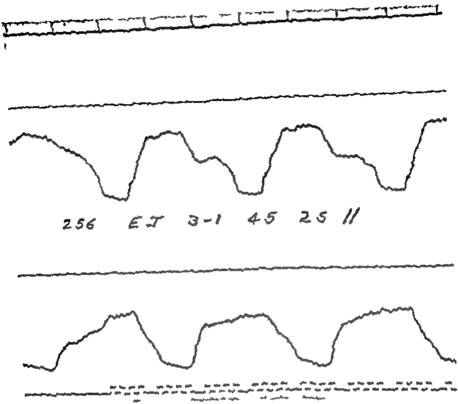


Figure 10 Gait recording 256 (Case 2) 3 weeks and 1 day after operation Cadence 65 2 sticks in phase

taken on the leg The recordings give information about the value of loading which neither the clinician nor the patient can otherwise estimate

*Case 3 Value of stick*

This case has been selected to demonstrate how useful information can be obtained quickly and simply from the gait recordings The recordings were made 64 weeks after an all cobalt chromium molybdenum alloy Stanmore total replacement of the left hip of a male patient aged 68 years He was virtually pain free and although advised to use a stick obviously walked without one He stated that he used the stick mostly to maintain balance and put little weight on it (estimated at 5 kg)

His gait was recorded both unaided and with a stick in his right

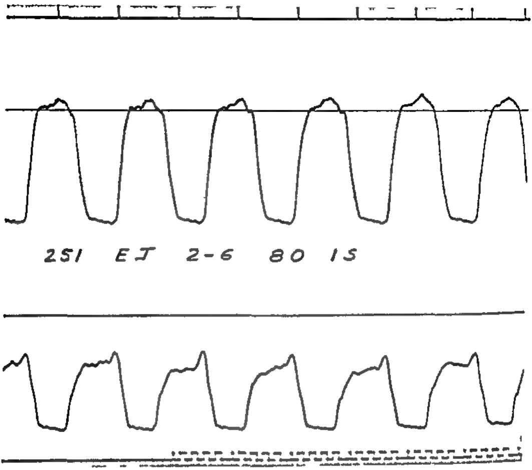


*Figure 9 Gait recording 251 (Case 2) 2 weeks and [redacted] days after operation, Cadence 80, 1 stick*

### *Case 4—First walk after operation*

One recording (Figure 13) of this patient has been selected as it shows the very first attempt to walk, using two crutches almost 3 weeks after operation for a custom-made femoral replacement The cadence was extremely low as one step took about 8 seconds Load was taken on the unaffected leg for 95 per cent of the step cycle Although the left foot was in contact with the ground for almost the same length of time, only a very small proportion of body weight was allowed onto the foot

### *Conclusion*

Recordings taken in the critical early stages after operation can assist the patient in mastering crutch techniques and avoid high loads being

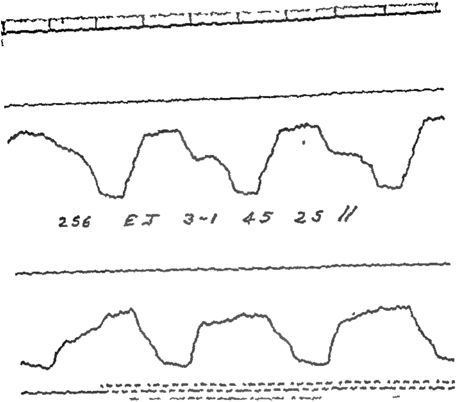


*Figure 10 Gait recording 256 (Case 2) 3 weeks and 1 day after operation, cadence 45, 2 sticks in phase*

taken on the leg. The recordings give information about the value of loading which neither the clinician nor the patient can otherwise estimate.

*Case 5 Value of stick*

This case has been selected to demonstrate how useful information can be obtained quickly and simply from the gait recordings. The recordings were made 64 weeks after an all cobalt-chromium-molybdenum alloy Stanmore total replacement of the left hip of a male patient, aged 68 years. He was virtually pain-free and although advised to use a stick, obviously walked without one. He stated that he used the stick mostly to maintain balance and put little weight on it (estimated at 5 kg).

His gait was recorded both unaided and with a stick in his right

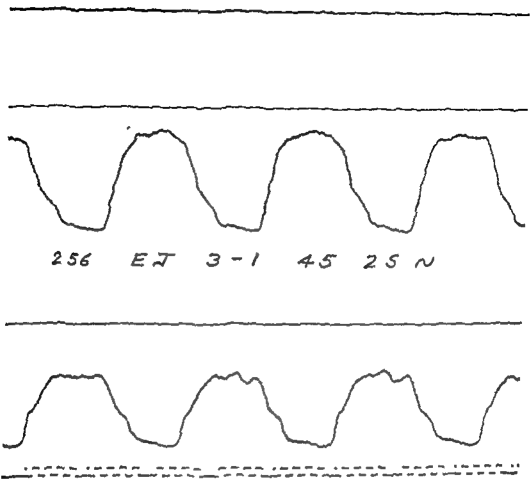


*Figure 11 Gait recording 256 (Case 2) 3 weeks and 1 day after operation, Cadence 45 2 sticks alternating*

hand These recordings are shown in Figure 14 The traces with a stick show the following factors, compared to walking unaided

1) There is a slight reduction in left load peaks
2) There is a slight increase in right load peaks
3) The left double peak toe load is eliminated
4) There is a deeper right inter-peak trough
5) The right heel and toe peaks are smoother, more rounded

*Conclusion*

This case illustrates clearly the value of the monitoring system

1) The advantage of continuing with the stick after 64 weeks is shown *Both left and right loadings are more even compared with* the gait when no stick is used

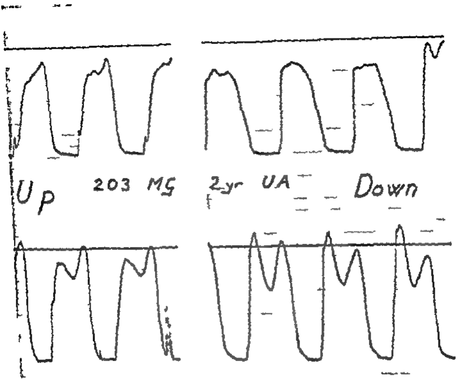


*Figure [illegible] Gait recording 203 (Case 3) 2 years after operation Up and down stairs unaided*

2) Evidence was provided that the surgeon judged correctly that a walking aid was required
3) The display of the trace to the patient should convince him of the necessity of following the surgeon's advice

*Progress chart*

The vertical component of the load transmitted through each foot can be measured and used to assess the clinical progress of a patient following treatment Average values of the maximum load obtained from measurements of the recordings of the gait of Case 1 over a period of 40 weeks are shown in Figure 15 The relative loading is shown and how it changes with different walking aids

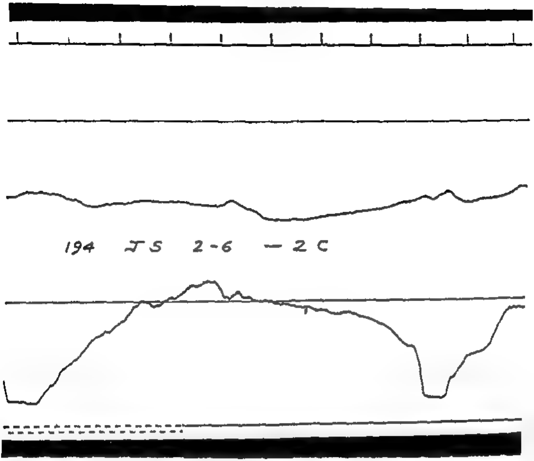


*Figure 13 Gait recording 194 (Case 4) 2 weeks and 6 days after operation, 2 crutches*

## GENERAL CONCLUSIONS

The recordings give the following information

1) the magnitude of the vertical component of the loads transmitted through the feet,
2) the characteristic gait or pattern of the loading,
3) the duration of the phases of the loading cycle,
4) the rate or cadence of walking,
5) the velocity of the patient

Observation and measurement of the above features of the recordings give the following clinical information about the patient

1) the proportion of body weight transmitted by the feet walking unaided and when using aids, and the changes in these loadings with time

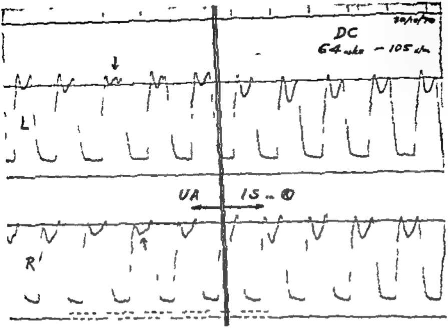


*Figure 14 Gait recording 356/357 (Case 5) 64 weeks after operation, Cadence 105, unaided/1 stick*

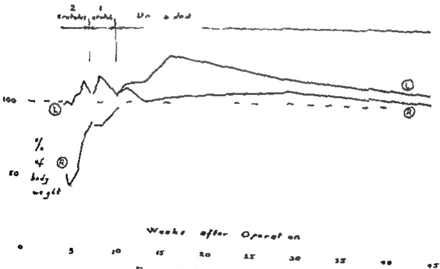


Figure 15 Progress chart (Case 1)

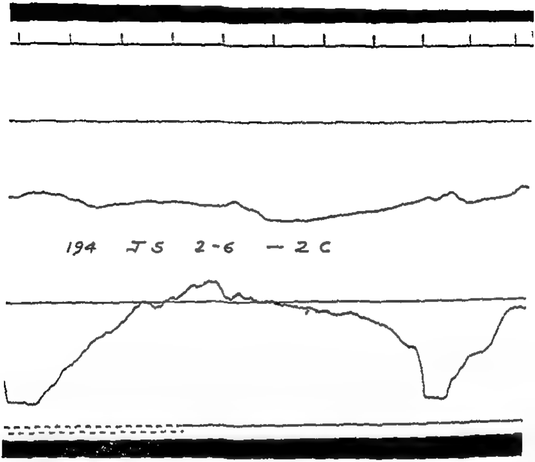


*Figure 13 Gait recording 194 (Case 4) 2 weeks and 6 days after operation, 2 crutches*

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*Key words* biomechanics force transducer joint replacement gait assessment load measuring footwear locomotion

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2) The relative value of heel and toe peak loadings
3) The absence, followed by the reappearance of heel and toe peak loadings and the order of this reappearance
4) The time over which the heel load rises, indicating the effect of the patient controlling the heel strike
5) The time over which the toe off action takes place, indicating the effect of the patient controlling this phase of the walk
6) The characteristic of the trough between the heel and toe peaks This loading can indicate the influence of the freedom or other wise of the other leg in its swing—non-weightbearing phase
7) The influence on the pattern of loading with alternative types and methods of use of walking aids
8) The influence of treatment on the rate or cadence of walking directly relatable to the cadence

The recordings have confirmed, contradicted and added to clinical observations In general, the sandal method has proved acceptable to the patients, who have been able to walk in an apparently normal manner The narrow corridor has provided a reassurance, both for physical support and lack of "public" observation and the length of the corridor has proved adequate in providing a sufficient number of steps

ACKNOWLEDGEMENTS

The assistance of the following is gratefully acknowledged

Department of Health and Social Security—for supporting the project with a grant

Royal Aircraft Establishment Instrumentation and Ranges Division—for producing the prototype system

Lloyd Instruments Limited Banbury Oxon—for undertaking the commercial production of a clinical system

Surgeons of the Royal National Orthopaedic Hospital—for their participation in the clinical trials

Staff of the Department of Biomedical Engineering Institute of Orthopaedics—for their participation in the control trials

Medical Photographic Department Institute of Orthopaedics—for producing the illustrations

Miss Leesa D MacDougall Department of Biomedical Engineering Institute of Orthopaedics—for secretarial assistance

Dunlop Footwear Limited Liverpool—for information concerning foot wear and the production of special sports shoes

Kistler Instruments Limited Farnborough—for the loan of the force platform

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*Key words* biomechanics, force transducer, joint replacement, gait assessment, load measuring footwear, locomotion

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Acta orthop scand 46, 896–905, 1975

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# A METHOD FOR RECORDING TENDON STRAIN IN SHEEP DURING LOCOMOTION

MARY KEAR & R N SMITH

*Accepted 17 xi 75*

Although more than a hundred reports have been published over the last century from experiments in which tendons have been artificially stressed to determine their physical properties, the authors are aware of only two reports of measurements of the mechanical behaviour of these structures during life (Shaw 1968, Barnes & Pinder 1974)

The importance of knowing how organised collagen behaves *in vivo* prompted this investigation to determine the mechanical strain imposed on a single tendon, and to correlate it with the activity of its muscle belly

## METHOD

The tendon of the forelimb lateral digital extensor of the sheep was used in these experiments The transducer (Figure 1) was a strain gauge 'bridge' made from a 30 mm × 3 mm strip of soft stainless steel 0 05 mm in thickness At each end 5 mm were bent back and a piece of 0 1 mm sprung stainless steel held between the two layers of thinner metal by epoxy resin The resultant structure consisted of two firm ends for attachment to the tissue and a flexible "bridge" between them A foil resistance strain gauge was bonded to the concave surface of the "bridge"

The strain gauge transducer was connected to form one arm of the Wheatstone Bridge circuit of an A C transducer meter The recorder was an ultra violet direct writing recording oscillograph The transducer was calibrated immersed in water at 38° C before implantation and after removal

To attach the transducer to the tendon an incision was made on the lateral aspect of the right forelimb along the metacarpus All loose connective tissue over the tendon was cleared its surface swabbed dry and cleaned with ether and the transducer then placed in position Braided stainless steel sutures were laid at each corner but not tightened Isobutyl 2 cyanoacrylate was applied between the proximal transducer flange and the tendon This bond was then held securely for 1 minute before being checked for adhesion after which the sutures were tied The distal flange was attached in the same way (Figure 1) The length of the flexible "bridge" was measured Lead wires from the transducer ran subcutaneously to a small skin incision over the animal's rib cage The incision accomodated a skin

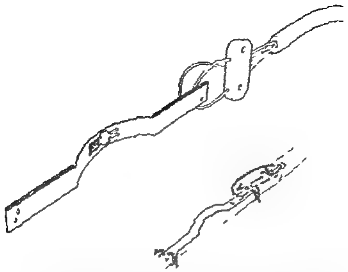

*Figure 1 The upper diagram shows the transducer used to record tendon strain A foil resistance strain gauge was bonded to the concave surface of the flexible metal bridge Either end of the bridge was glued and sutured to the tendon as shown in the lower diagram A small epoxy resin flange holding the lead wires was sutured close to the transducer*

socket similar to that described by Lanyon (1971 a) A hard rolled 0 15 mm stainless steel cover screwed to the metacarpus protected the instrument from skin pressure

Daily recordings were taken from 14 animals Limb position was recorded on slow motion film (64 frames per second) and by a variable inductance linear accelerometer as used by Lanyon (1971 b) In five cases simultaneous recordings of electromyographic potentials were made using fine wire electrodes implanted in the lateral digital extensor muscle (Kear & Smith 1972)

At the end of each experiment with the animal anaesthetised the tendon was dissected out and the transducer checked qualitatively to ensure it was still functioning correctly The muscle was also electrically stimulated and a transducer record made In one case the humerus was securely fixed and the distal end of the tendon was connected to a force transducer and recordings taken from both instruments as the muscle was stimulated

In every case a postmortem histological examination was made of the tissue to which the instrument had been attached

## RESULTS

The recordings were very similar, both between animals and from the same animal at different speeds

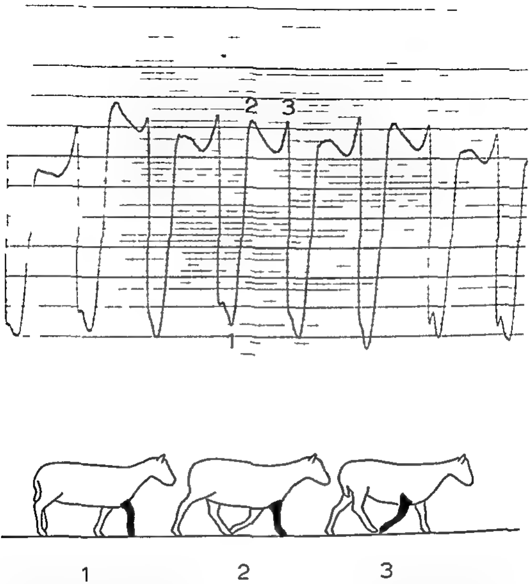


*Figure 2 Part of a trace recorded from a walking animal which had a strain gauge transducer attached to the lateral digital extensor tendon Each strain change cycle represents one stride during which three points can be recognised Between points 1 and 2 there is a sharp increase in tendon strain as the foot is placed on the ground and weight taken on it A slight reduction in tension is recorded as the body swings forward but strain is transiently reimposed at point 3 when the foot leaves the ground*

A typical recording is shown in Figure 2 An increase in length of the transducer is indicated by an upward deflection of the trace and a decrease in length by a downward deflection Each stride was marked by a strain change cycle Three distinct points could be identified in each cycle and these are indicated with the corresponding limb position When the foot was placed on the ground and weight taken on it, there was an apparent tension in the tendon As the body swung forward this tension was slightly reduced, transiently reimposed and then completely released

The height of each trace indicates the degree of extension of the transducer and from this an estimate could be made of the strain which occurred in the tendon at each stride The tendon strain varied from animal to animal and to a lesser extent in the same animal on different days, but in each case strain tended to increase with the speed of locomotion Ten strides were measured on each day at each of four speeds and the resultant mean strains and standard deviations for each animal over the experimental period are given in Table 1

*Table 1 The mean tendon strain (per cent) for each animal over the experimental period*

| Animal | Slow walk | Med walk | Fast walk | Trot |
|---|---|---|---|---|
| 1 | 12 ± 4 | 12 ± 4 | 1.5 ± .5 | 20 ± 7 |
| 2 | 08 ± 4 | 11 ± 7 | 1.3 ± 4 | 14 ± 6 |
| 3 | 08 ± 3 | 07 ± 3 | 09 ± 3 | 11 ± 6 |
| 4 | 15 ± 3 | 15 ± 3 | 18 ± 5 | 24 ± 8 |
| 5 | 11 ± 6 | 17 ± 7 | 21 ± 5 | 22 ± 6 |
| 6 | 17 ± 7 | 18 ± 9 | 20 ± 5 | 26 ± 5 |
| 7 | 16 ± 4 | 17 ± 3 | 19 ± 4 | ---- |
| 8 | 05 ± 1 | 0.3 ± 0 | 06 | 06 |
| 9 | 11 ± 3 | 14 ± 5 | 10 ± 3 | 10 ± 3 |
| 10 | 08 ± 3 | 09 ± 3 | 11 ± 6 | 10 ± 3 |
| 11 | 07 ± 5 | 11 ± 4 | 13 ± 5 | 15 ± 4 |
| 12 | 05 ± 3 | 06 ± 3 | 06 ± 3 | 08 ± [illegible] |
| 13 | 06 ± 2 | 08 ± 2 | 09 ± 1 | 14 ± 1 |
| 14 | 08 ± 2 | 10 ± 2 | 11 ± 3 | 17 ± 3 |

The rate at which the tendon was strained during each cycle varied from nil to a maximum shown in Table 2 However, these maximum rates were recorded for only about one tenth of a second during each stride, as the animal walked fast or trotted

*Table 2 Maximum strain rates recorded for each animal*

| Animal | Maximum recorded strain rate (per cent per second) |
|---|---|
| 1 | 29 9 |
| 2 | 17 2 |
| 3 | 15 0 |
| 4 | 43 8 |
| 5 | 26 1 |
| 6 | 31 4 |
| 7 | 25 8 |
| 8 | 5 4 |
| 9 | 9 0 |
| 10 | 10 9 |
| 11 | 10 2 |
| 12 | 11 4 |
| 13 | 13 4 |
| 14 | 21 4 |

Figure 3 shows a typical record from an animal during a trot with a strain gauge transducer attached to the tendon and two sets of electromyographic electrodes implanted in the muscle The strain change pattern shown here is similar to that shown in Figure 2 The bursts of muscle activity occurred mainly during two phases of each stride The most consistent period of activity occurred during the main tension phase in the tendon as the leg was protracted and the foot extended to be placed on the ground The second burst occurred as the foot was lifted from the ground about the time when there was also a slight increase in tendon strain

At the end of each experiment, stretching the tendon either manually or when the muscle contracted, produced a normal record from the transducer

When the force transducer was used, a load of 4 5 kg was recorded simultaneously with a tendon strain of 2 3 per cent, imposed at a rate of 11 5 per cent per second Strains of a similar size and rate had been previously recorded from the transducer during normal locomotion

At postmortem examination the tendon did not appear to have been grossly damaged, although the whole area under examination was covered by a gelatinous pad of inflammatory tissue This may in fact have helped to protect the instrument There was however a very slight cellular infiltration between tendon fibres in a few places, notably

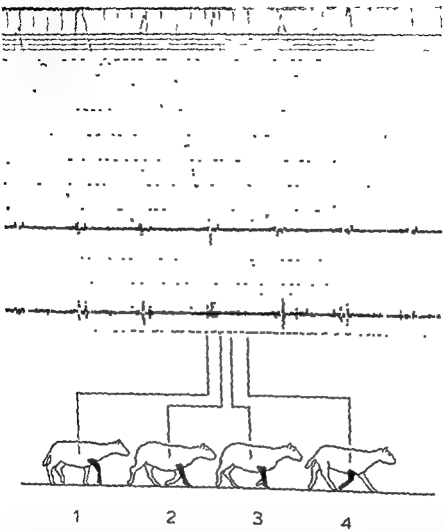


*Figure 3.* *Part of a recording taken from a trotting animal in which both a strain gauge transducer and electromyographic electrodes had previously been implanted. Muscular contraction occurred mainly during one particular phase of the stride, during the period of tendon stretching as the foot was placed on the ground (between points 1 and 2). There was a second less consistent period of activity as the foot was lifted from the ground (between points 3 and 4).*

around the sutures In some cases there was a small amount of infiltration between the surface of the tendon and the layer of adhesive, although this did not appear to be related to the length of time the instrument had been implanted or to the size of the strain which had been recorded

## DISCUSSION

This series of experiments was fraught with many problems that could have affected the accuracy of the results

It is unlikely that the bond between transducer and tendon did transmit 100 per cent of the change in length which occurred, especially as in some cases cells had found their way between the glue layer and the tendon surface

It is possible that sometimes when the transducer indicated a shortening the tendon may have bowed slightly without actually *decreasing its length While the limb was being lifted forward* during the swing phase (between points 4 and 1 in Figure 3) there was an apparent rapid and marked shortening of the tendon It is possible that in this flexed position tendon bowing may have occurred

It was assumed in taking simultaneous electromyographic and strain readings that the instrument lag on the two systems was identical This is probably justifiable but may not have been absolute

It seems likely that the cause of the periods of tendon stretch was due, at least in part, to muscular contraction and electromyographic potentials were recorded during both these periods of tendon strain

A more detailed explanation of muscle activity as related to limb position and tendon strain would require simultaneous recordings from several muscles

However, although far from ideal this technique did produce reasonably consistent results from a number of animals and in this respect it is an advance on those previously reported Shaw (1968) did not measure tendon strain but tendon load and this he accomplished by substituting a strain gauge for a section of the superficial digital flexor tendon in a dog He obtained a peak load of 0 6 kg while the animal was standing and 1 0 kg as it walked It was suggested that these values were lower than normal as the animal was not putting full weight on the leg Barnes & Pinder (1974), also wishing to measure tendon tension, attached a buckle transducer to the common digital extensor tendon in a single horse They published a trace of tension measured in

the tendon during four strides The tension appeared to increase during the period in which the foot was extended and brought to the ground It reached its highest point just after impact The tension then declined and remained at a relatively low level throughout the support phase, to be re imposed as the limb was protracted The maximum tension was 170 N (17 3 kg) but the normality of gait was somewhat suspect

It is difficult to decide whether or not the results from this work support previous *in vitro* studies, as the conditions found *in vivo* are quite different from those used in most of the *in vitro* work Harkness in 1968 considered the rate of tendon stress *in vivo* to be very rapid, and this type of loading of tissues under experimental conditions has been little studied Only the properties of tendon found when forces are applied slowly over a discrete period of time have been well documented These experiments have been carried out without particular regard to physiological conditions, despite the considerable effect that experimental conditions have been shown to produce (Chvapil et al 1962, Rigby et al 1959) A typical stress/strain curve produced in such experiments (Elliott 1967) has an initial "toe" portion where the tissues are easily extensible It is in this region that Harkness (1961) and Stucke (1950) believe that tendon reacts in life With an increase in stress the "toe" is followed by a straight portion over which the tendon is elastic Abrahams (1967) and Rigby et al (1959) believe it is in this region that tendon normally reacts *in vivo* Beyond the proportional limit the tissue begins to creep and finally ruptures

If one can relate such *in vitro* studies to circumstances in life, the absolute limit of strain which could normally occur without permanent damage to the tendon must be the proportional limit This appears to be between 2 and 5 per cent strain (Abrahams 1967, Elliott 1967, Gratz 1937, Gratz & Blackberg 1935, Rigby et al 1959, Stucke 1950) Harris et al (1964) consider that tendon is probably never stressed, *in vivo*, to greater than one-fourth its ultimate strength They consider the limit of stress *in vivo* to be 2 5 kg/mm² According to their experiments elongation is 2 5 per cent at this level of stress

From the work described in this paper the maximum strain recorded in the lateral digital extensor tendon was 2 6 per cent while the sheep was trotting This would agree with expectations However, any use of these findings in a consideration of tendon degeneration and rupture should take into account that these occur almost exclusively in flexor tendons whose mechanical circumstances may be very different from those of the extensors

## SUMMARY

Strain change in the lateral digital extensor tendon of sheep was measured during locomotion by means of a small metal strain gauge transducer. The strain pattern was correlated with the activity of the muscle and the position of the limb.

The main period of tendon strain occurred immediately following a phase of muscle activity as the foot was placed on the ground. A second period of tendon tension occurred as the foot was lifted from the ground This was again usually associated with a muscular contraction.

Daily recordings were taken from 14 animals for about 10 days after implantation of the transducer.



## ACKNOWLEDGEMENTS

This work was made possible by a grant from the Horserace Betting Levy Board to whom we are most grateful We would like to thank Dr L E Lanyon for his help throughout the experiments and Dr M J Bojrab for his help in anaesthetising the animals


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*Key words* tendon strain biomechanics locomotion

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# ETIOLOGICAL FACTORS IN OSTEOCHONDRITIS DISSECANS

## *An Experimental Study into the Etiological Factors in Osteochondritis Dissecans in the Canine Humeral Head using Overloading With and Without Somatotropin and Thyrotropin Hormone Treatment and Mechanical Trauma*

S Paatsama, P Rokkanen & J Jussila

Accepted 24 xi 75

In a previous study, the canine humeral head in the early stage of osteochondritis dissecans (o d ) displayed irregular arrangements of cells lacking nuclei in the germinative zone of the thickened articular cartilage and an intercartilaginous cleavage with bridge formations (Paatsama et al 1971 a) There were thick bone trabeculae subchondrally and bone regeneration In the advanced stage a loose fragment of articular cartilage or ossified cartilage was found In the late stage there was more granulation tissue, ossifying cartilage and new bone, and there were osteophyte formations

The study of four growing dogs treated from the age of 6 weeks with somatotropin (500 IU), thyrotropin (94 IU) or corticotropin (1400 IU) over a period of 10 weeks revealed changes resembling the early stage of spontaneous o d (Paatsama et al 1971 b) Because somatotropin and thyrotropin are known to have an influence on the articular cartilage and a stimulating effect on bone growth, the results of this latter study indicated that a changed and thickened articular cartilage, particularly in the weightbearing surface, is hardly capable of contributing to the bone remodelling and external influences during the progressive growth period

Trauma has played an important role as an etiological factor of o d (e g Craig & Riser 1965, Leonard 1971) This same conclusion was found experimentally by Tallquist (1962) Therefore, a further study was made to investigate the etiological factors of o d in the canine

humeral head, using overloading and mechanical traumas of the weightbearing joint cartilage and/or bone Overloading was used with and without somatotropin and thyrotropin hormone treatment

## MATERIAL AND METHODS

The material (Table 1) consisted of two groups of growing dogs A) dogs having overloading with somatotropin (3 dogs) or thyrotropin (3 dogs) treatment, and overloading without hormone treatment (16 dogs) and B) a group of 13 dogs with mechanical trauma thus giving 35 dogs in all Fifteen dogs were used as controls two Labradors one treated with somatotropin and the other with thyrotropin and 13 healthy dogs (11 of them originating from the investigations mentioned in the introduction)

*Group A* Six Labrador retrievers underwent myotomy of the M biceps brachii of the right foreleg resulting in overloading of the contralateral limb The dogs were 4 months old at the beginning of the experiment when the hormone treatment began Three of the dogs were treated with a total dosage of somatotropin* of 500 IU and the other three with thyrotropin* 160 IU divided into equal doses and administered daily for 5 days weekly for 16 weeks The myotomy was performed 4 8 and 12 weeks after the beginning of the hormone treatment The dogs were sacrificed 4 8 and 12 weeks post operatively when all the dogs were at the age of 8 months (The two hormone treated Labradors used as controls were littermates of the previously mentioned six dogs the hormone dosage and time of sacrifice were the same )

The group of 16 dogs with overloading alone consisted of two Labrador retrievers and 14 mongrel dogs of medium size aged 3–6 months at the beginning of the investigation when the myotomy was performed The dogs were sacrificed 10–18 weeks post-operatively at the age of 8–9 months

*Group B* Mechanical trauma of the joint cartilage or joint cartilage and/or epiphyseal bone were performed on the humeral heads of 13 dogs (four Labrador retrievers and nine mongrel dogs of medium size) aged 5–6 months at the time of the operation The traumas resembled the defects found in spontaneous o d The post operative observation period was 2 18 weeks (sacrificed at 2 weekly intervals)

All dogs were kept in the Small Animal Clinic of the College of Veterinary Medicine and fed with a controlled and restricted diet of balanced dry food canned meat mineral and vitamin supplement

Clinical and radiological examinations were performed at 2 weekly intervals The specimens taken for microstructure study were sectioned in the sagittal plane after autopsy The histological specimens were fixed in 10 per cent neutral formalin and decalcified by the EDTA method Staining was performed with *Haematoxylin Eosin* and Alcian Blue

For oxytetracycline (OTC) fluorescence studies the dogs received oxytetracycline** iv 20 mg kg body weight 2 days prior to sacrifice The specimens to be used

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* Standardized hormones Ferring Somacton® Lagen somatotropin 50 IU
Actyron® Lagen thyrotropin 5 IU

** Pfizer Terramycin®

*Table 1 Changes as a result of overloading with or without hormone treatment and mechanical trauma resembling spontaneous osteochondritis dissecans in an early stage*

| Group/ number of dogs | Number/breed | Over-loading | Hormone treatment | Mechanical trauma | Age at the start (months) | Age when sacrificed (months) | Changes |
|---|---|---|---|---|---|---|---|
| A (22 dogs) | 3 Labradors | + | Somatotropin 500 IU | — | 4 | 8 | ++++ |
| | 3 Labradors | + | Thyrotropin 160 IU | — | 4 | 8 | +++ |
| | 2 Labradors | + | — | — | 3–6 | 8–9 | + |
| | 14 mongrels | + | — | — | 3–6 | 8–9 | — |
| B (13 dogs) | 4 Labradors | — | — | + | 5–6 | 6–10 | — |
| | 9 mongrels | — | — | + | 5–6 | 6–10 | — |
| Controls (15 dogs) | 1 Labrador | — | Somatotropin 500 IU | — | 4 | 8 | ++ |
| | 1 Labrador | — | Thyrotropin 160 IU | — | 4 | 8 | ++ |
| | 13 healthy mongrels | — | — | — | - | 4–12 | — |

++++ most severe changes
+++ severe changes
++ moderate changes
\+ slight changes

Assessed radiologically, histologically, microradiologically and with OTC bone labelling


*Figure 1 Radiographs of the shoulder joint of a Labrador retriever A at the age of 4 months at the time of commencement of somatotropin treatment B after 4 weeks overloading and 8 weeks somatotropin treatment showing increased radiodensity subchondrally flattening of the humeral head and lipping of the epiphyseal margin*

In the OTC bone labelling and microradiographic studies were hardened in methyl metacrylate and ground to a thickness of 100 μ. In the microradiographic studies 2[illegible] kV and 18 mA were used along with an exposure time of 10 min and a film focal distance of 10 cm

## RESULTS

### I *The dogs with overloading*

Radiologically the overloaded humeral heads of the hormone treated dogs particularly the three somatotropin treated dogs showed flattening of the epiphysis increased radiodensity subchondrally and lipping of the epiphyseal margin during an observation period of from 4 6 weeks (at an age of 20 26 weeks) (Figure 1 B) Histologically the thick articular cartilage displayed degeneration and irregular arrangements of the cells in places small cleavages in the germinative zone and also basally (Figure 2 A) The epiphyseal cartilage showed similar changes metachromatically staining mass and cyst formations the palisading columns were irregular and in places non existent (Figure 2 B) The cartilaginous changes were more severe in the overloaded humeral head of the somatotropin treated Labradors Microradiographs revealed thick bone trabeculae subchondrally, particularly proximally in the

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| | 2 Labradors | + | — | — | 3–6 | 8–9 | + |
| | 14 mongrels | + | — | — | 3 6 | 8 9 | — |
| B | 4 Labradors | — | — | + | 5–6 | 6–10 | — |
| (13 dogs) | 9 mongrels | — | — | + | 5–6 | 6–10 | — |
| Controls | 1 Labrador | — | Somatotropin 500 IU | — | 4 | 8 | ++ |
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| | 13 healthy mongrels | — | — | — | - | 4–12 | — |

++++ *most severe changes*
+++ *severe changes*
++ *moderate changes*
+ *slight changes*

Assessed radiologically, histologically, microradiologically and with OTC bone labelling


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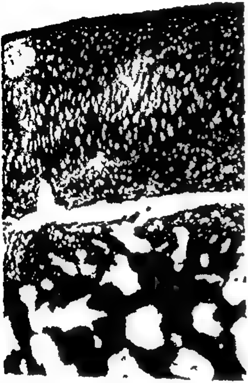

*Figure 3 Micrograph of the humeral head of an 8 month old Labrador retriever suffering from the early stage of spontaneous ... d thick and degenerated articular cartilage and cleavage of the germinative zone Alcian Blue × 48*

*B Dogs with mechanical trauma*

Radiologically a thickening of the subchondral bone after the cartilaginous trauma was observed *from 4 weeks post operatively* the humeral heads subjected to bone trauma displayed extensive radiodensity and remodelling in the trauma area Radiodensity of the metaphysis and uneveness of the traumatic *articular* surface was noted later during the observation *period Histologically* the cartilaginous trauma displayed remodelling *between the* traumatic and intact cartilage without signs of *degeneration (Figure 5 A)* The bone trauma in the humeral head showed *regeneration* connective tissue, chondrocytes cartilaginous metamorphosis and bone regeneration without signs of degeneration (Figure 6 A) Microradiographs displayed thickening of the bone trabeculae subchondrally *and* in the metaphysis ...ntinuing towards the diaphysis and *bridge* formation in the epiphyseal cartilage (Figure 7 A) In the *changed* areas the OTC uptake was significant (Figure 7 B) Microradiographically, the subchondral

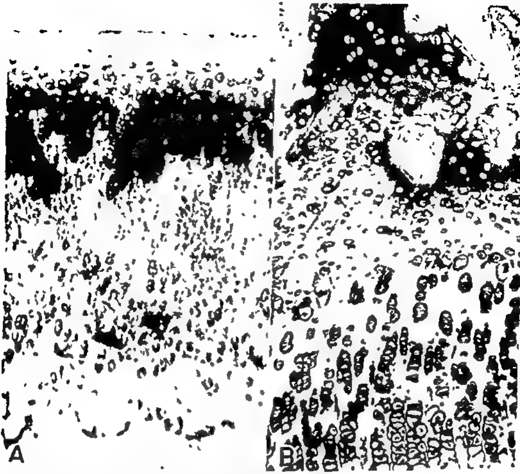


*Figure 2 A & B Micrographs of a humeral head of a Labrador retriever 8 months old (after 12 weeks overloading and 16 weeks somatotropin treatment). A, showing thick, degenerated articular cartilage, and cleavages of the germinative zone and basally B, the corresponding changes of the geminative zone of the epiphyseal cartilage, with irregular palisading columns. Alcian Blue, × 84*

overloaded humeral head of the somatotropin-treated dogs (Figure 4 A) OTC uptake was strong subchondrally, particularly in the changed proximal area (Figure 4 B).

Radiologically, the overloaded humeral epiphyses of the two Labrador retrievers from the 16 dogs without hormone treatment displayed increased subchondral radiodensity during an observation period of from 4–8 weeks, in the 14 medium-sized mongrel dogs no such changes were observed. Histologically, none of the dogs showed any degenerative changes in the articular or epiphyseal cartilage Microradiography and OTC bone labelling showed no changes

*Figure 5 Micrographs A of the humeral head of a 9 month old mongrel dog (the cartilaginous trauma was made 8 weeks earlier) showing a cartilaginous remodelling between the traumatic and intact cartilage B the same area of spontaneous o d showing degeneration Alcian Blue A × 62 B × 48*

and epiphyseal bone traumas displayed regeneration and functional remodelling (Figure 8 A & B), centrally, the bone trabeculae were in places small in number The thick metaphyseal bone trabeculae continued towards the diaphysis and OTC uptake was strong in the changed areas

## DISCUSSION

Radiologically the overloaded humeral heads of the six hormone-treated Labrador retrievers displayed increased radiodensity subchondrally as well as flattening and marginal lipping at the age of 20 26 weeks (observation period of from 4 6 weeks) (Figure 1 B) Similar changes were observed in dogs suffering from spontaneous o d in its early stage (Paatsama et al 1971 a) The overloaded humeral head of the two Labradors without hormone treatment showed radiodensity during an observation period of from 4 6 weeks, but no flatten-

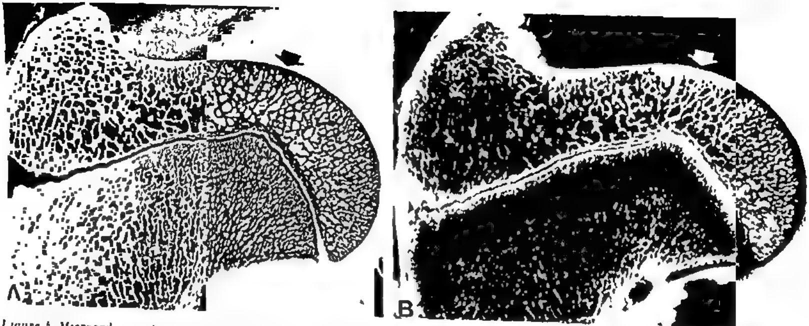


*Figure 4 Microradiograph (A) and fluorescent micrograph (B) from the same dog as in Figure 1 at the age of 8 months (after overloading 8 weeks and somatotropin treatment 12 weeks) A, showing thickened bone trabeculae subchondrally, particularly in the proximal area (arrow) B, showing OTC uptake particularly in the proximal area*


*Figure 5 Micrographs A of the humeral head of a 9 month old mongrel dog (the cartilaginous trauma was made 8 weeks earlier) showing a cartilaginous remodelling between the traumatic and intact cartilage B the same area of spontaneous o d showing degeneration Alcian Blue A × 72 B × 48*

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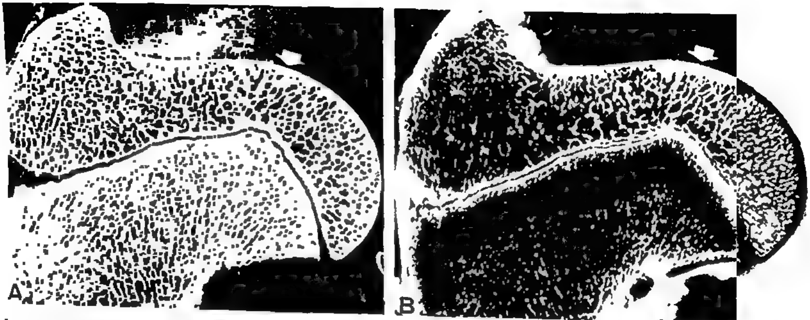


*Figure 4 Microradiograph (A) and fluorescent micrograph (B) from the same dog as in Figure 1 at the age of 8 months (after overloading 8 weeks and somatotropin treatment 12 weeks) A, showing thickened bone trabeculae subchondrally, particularly in the proximal area (arrow) B, showing OTC uptake particularly in the proximal area*


*Figure 7 Microradiograph (A) and fluorescent micrograph (B) of the humeral head of a Labrador retriever, 8 months old, with mechanical trauma of the joint cartilage (8 weeks post-operatively) showing thickened bone trabeculae subchondrally and in the metaphysis continuing towards the diaphysis, and bridge formations through the epiphyseal cartilage B, the changed areas and bridge formations show OTC uptake, a strong uptake continues towards the diaphysis*

*Figure 2 Micrographs A of the humeral head of a 9 month old mongrel dog (the cartilaginous and bone trauma was made 16 u eeks earlier) showing bone and cartilaginous regeneration and cartilaginous metamorphosis extending to the joint surface B spontaneous o d status 10 u eeks post operatively showing bone and cartilaginous regeneration and metamorphosis but also degeneration of joint cartilage (arrow) H F × 25*



ing or marginal lipping In the overloaded humeral head of the other 14 medium sized mongrel dogs no such changes were observed This might indicate reactive differences between the breeds of different growth characteristics particularly when subjected to the same stress factors with similar care and feeding

Histologically, the overloaded head of the three somatotropin treated Labradors displayed the most severe changes thickened and de generated articular cartilage and small cleavages in the germinative zone and also basally (Figure 2 A) resembling changes in spontaneous o d (Figure 3) (Paatsama et al 1971 a) The changes resembling spontaneous o d in the joint and epiphyseal cartilage (Figure 2 B) were similar in this study (eight Labradors treated with 500 IU somatotropin or 160 IU thyrotropin) to those in the earlier study by Paatsama et al (1971 b) (four Beagle mongrel dogs treated with 500 IU somato

tropin 94 IU thyrotropin or 1400 IU corticotropin) although the dogs were of different breeds and the treatment differed in total doses, and dose combinations and periods The results further confirm the opinion that hormonal influences play an important role as an etiological factor in o d as discussed by Palmer (1970) Ljunggren et al (1971) and in the earlier study (Paatsama et al 1971 b)

Microradiologically, the overloaded humeral head particularly of the three somatotropin treated Labradors displayed subchondrally a clearly distinguished area of thick bone trabeculae proximally (Figure 4 A) OTC bone labelling revealed significant uptake in the changed area (Figure 4 B) The overloaded humeral head of the 16 dogs without hormone treatment showed no such changes This might indicate that overloading as an external factor alone is not able to produce changes in the humeral head a changed tissue (internal factor in this study caused by hormone treatment) is also needed Why the overloading produced changes more proximally and not in the place of spontaneous o d was probably due to the fact that this wearing point of the joint surface became more highly stressed

Radiologically, the mechanical trauma of the articular cartilage and/or epiphyseal bone showed the most prominent changes, viz increased radiodensity subchondrally, in the bone trauma area and in the metaphysis During the observation period the bone traumas resulted in regeneration without signs resembling spontaneous o d Histologically, the mechanical trauma of the joint cartilage showed remodelling between the traumatic and intact cartilage (Figure 5 A) and no degeneration as in spontaneous o d (*Figure 5 B*) The bone traumas displayed extended cartilaginous and bone regeneration (Figure 6 A) similar to the slight healing process of spontaneous o d and cartilaginous degeneration (arrow *Figure 6 B*) Microradiographically the humeral head with cartilaginous trauma displayed thick bone trabeculae subchondrally, and in the epiphysis and metaphysis (Figure 7 A) The changed areas showed OTC uptake continuing towards the diaphysis as a sign of regeneration and functional remodelling (Figure 7 B) The subchondral and deeper epiphyseal bone traumas showed functional healing and remodelling (Figure 8 A and B) differing from that in spontaneous o d (Figure 8, C and D) The mechanical traumas in the humeral heads of all the 13 operated dogs did not result in changes resembling those of spontaneous o d as observed by Tallquist (1962) in an experimental study in the rabbit knee joint

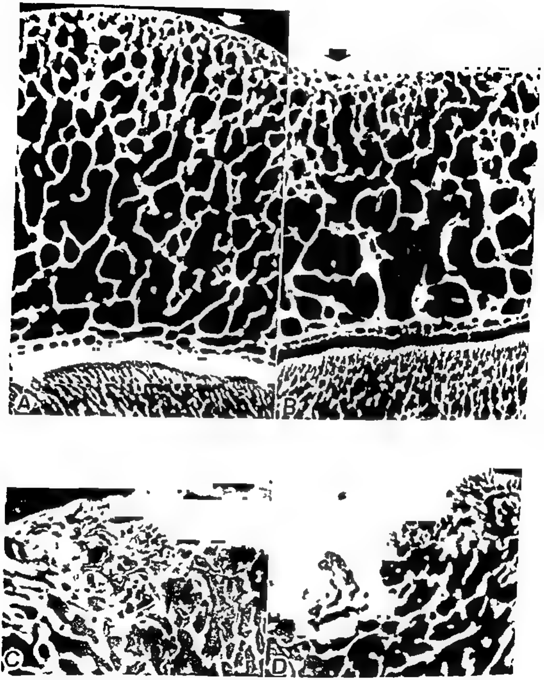


*Figure 8 Microradiographs (A & B) of two mongrel dogs aged 8 months A the mechanical subchondral trauma made 14 weeks earlier showing functional bone remodelling and thickening of the bone trabeculae of a larger epiphyseal area B a deep epiphyseal mechanical trauma made [illegible] weeks earlier showing functional healing thick bone trabeculae and more centrally absence of trabecular structure C, spontaneous o d in an advanced (dissecans) stage and D spontaneous o d 10 weeks post operatively showing slight regeneration*

Acta orthop scand. 46 919 925 1975

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# SYNOVIAL CHONDROMATOSIS

J H CHRISTENSEN & J O POULSEN

Accepted 4 xi 75

Synovial chondromatosis is a rare disease when considered in the specific sense that it is a condition in which islands of cartilage are produced by the synovial membrane This cartilage is produced in submesothelial foci (Aegerter & Kirkpatrick 1968) where the cells undergo metaplasia to chondroblasts These foci become pedunculated and may be separated from their pedicles as loose bodies in the joint Synovial chondromatosis may be confused with other causes of loose bodies such as degenerative joint disease, tuberculous arthritis, osteochondritis dissecans and neurotrophic arthritis In cases with a characteristic X ray picture the diagnosis may be easy, but if the X ray is normal the patient is often deprived of the proper treatment There fore we have found it justifiable to publish a report on this condition based on patients seen in our ward, outlining the symptoms and clinical signs

## MATERIAL

The report studies 22 patients seven females and fifteen males with synovial chondromatosis diagnosed at the Orthopaedic Hospital in Aarhus during the period 1970 1973 Sixteen patients five females and eleven males were operated on Age distribution is shown in Figure 1 The localization was in the knee for fourteen cases in the hip for six and in the elbow for three The investigation is retrospective and the results of treatment were ascertained on the basis of the notes two and a half years on average after the operation or after the first visit in the case of those not operated on In the group operated on the diagnosis was established by biopsy in seven cases and microscopy showed numerous cartilaginous foci in the synovial membrane In nine cases the macroscopic changes during the operation were entirely characteristic with loose bodies being discovered and roughness of the synovial membrane being felt Cases with multiple free bodies but without changes in the synovial membrane were excluded. In the group not operated on the diagnosis was made from a characteristic X ray with several free bodies and periarticular calcification The patients were seen by various physicians in the outpatient clinic both before and after treatment

## SUMMARY

The overloaded humeral heads of the six growing Labrador retrievers treated with somatotropin and thyrotropin hormone showed the most pronounced changes of the articular cartilage and subchondral bone, resembling changes in the early stage of spontaneous osteochondritis dissecans The overloading alone used in 16 dogs without hormone treatment produced no changes, except that two Labrador retrievers showed increased radiodensity subchondrally during the first 4 6 weeks of the observation period The mechanical traumas of the articular cartilage and the epiphyseal bone regenerated and did not result in changes resembling those of spontaneous osteochondritis dissecans



## ACKNOWLEDGEMENTS

This study was supported by a grant from the National Research Council for the Medical Sciences

English text checked by D B Bulliwant Helsinki


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*Key words* osteochondritis dissecans


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*Table 3 X ray changes in the group operated on*

| | Loose bodies without periarticular calcifications | Loose bodies and periarticular calcifications | No abnormality |
|---|---|---|---|
| Knee | 2 | 3 | 6 |
| Hip | | 3 | 0 |
| Elbow | | 3 | 0 |

*Table 4 Operative treatment*

| | Removal of loose bodies | Removal of loose bodies and partial synovectomy |
|---|---|---|
| Knee | [illegible] | 5 |
| Hip | [illegible] | 3 |
| Elbow | 3 | 0 |

*Table 5 Results in the group operated on*

| | No or negligible symptoms | Unchanged symptoms | Recurrence |
|---|---|---|---|
| Knee | 5 | 2 | 3 |
| Hip | 1 | 1 | 1 |
| Elbow | 2 | – | 1 |

cases with normal X rays, it was possible to detect a free body clinically

In seven cases without characteristic X-rays the *diagnosis* was confirmed at the operation Four of these patients *were operated on* because of a suspected lesion of the meniscus and three because of a suspected free body The group not operated on only included patients with characteristic X-rays In no case was the *diagnosis* established on physical findings alone In the group not operated on, one patient did not want an operation in another case it was *decided* not to operate because of advanced age while four *patients* had only negligible symptoms

Eight patients were treated by simple removal of the free bodies and in eight patients partial synovectomy was performed as well (Table 4) The disease recurred in five patients (Table 5) In one case this happened after 10 years, but as the patient had few and intermittent

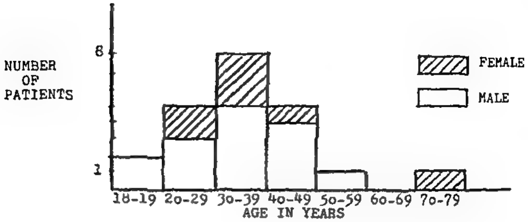


*Figure 1 Age distribution*

## RESULTS

The patients had frequently had symptoms for several years before the diagnosis was established (3 years and 2 months on average) The most frequent complaints were joint pain, swelling and a sensation of stiffness of the joint (Table 1) while the most frequent physical signs were limited movement, swelling and crepitation (Table 2) In the group operated on, we found characteristic X-rays in nine cases, in six cases there were normal X-rays and in one case a free body was found in the X-ray without periarticular calcification (Table 3) In two of the

*Table 1 Symptoms*

| | Pain | Stiffness | Swelling | Loose bodies | Locking |
|---|---|---|---|---|---|
| *Knee* | 13 | [illegible] | 11 | 3 | 3 |
| Hip | 6 | 0 | 0 | [illegible] | 1 |
| Elbow | 3 | 3 | 1 | 0 | 2 |

*Table 2 Physical signs*

| | Tenderness | Synovial thickening | Swelling | Crepitus | Limitation of movement | Loose bodies |
|---|---|---|---|---|---|---|
| Knee | 5 | 2 | 6 | 7 | 9 | 6 |
| Hip | 0 | – | | – | 6 | – |
| Elbow | 1 | 0 | 1 | 1 | 3 | 1 |

*Table 3 X ray changes in the group operated on*

| | Loose bodies without periarticular calcifications | Loose bodies and periarticular calcifications | No abnormality |
|---|---|---|---|
| Knee | 1 | 3 | 6 |
| Hip | | 3 | 0 |
| Elbow | | 3 | 0 |

*Table 4 Operative treatment*

| | Removal of loose bodies | Removal of loose bodies and partial synovectomy |
|---|---|---|
| Knee | 5 | 5 |
| Hip | 0 | 3 |
| Elbow | 3 | 0 |

*Table 5 Results in the group operated on*

| | No or negligible symptoms | Unchanged symptoms | Recurrence |
|---|---|---|---|
| Knee | 5 | 2 | 3 |
| Hip | 1 | 1 | 1 |
| Elbow | 2 | – | 1 |

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Figure 2 Three typical cases of synovial chondromatosis verified by biopsy

symptoms no indication was found for reoperation. Two patients were offered a further operation, but declined. One patient had a second operation and improved whilst in the remaining case treatment was deferred.

## DISCUSSION

The condition has been given various names, synovial osteochondromatosis, synovial osteochondromata, osteochondromatosis, joint chondroma, diffuse enchondroma and synovial chondrometaplasia. The authors feel that synovial chondromatosis is a convenient name, because the report includes cases without X-ray changes, but with a positive biopsy or characteristic changes in the synovial membrane at the time of operation. The disease is seen most frequently in the third, fourth and fifth decades and is seen twice as often in men as in women. It is frequently localized in the knee joint, but may appear in any joint and bursa. Age distribution and localization in our patients is in accordance with the findings of other authors (Jeffreys 1967, Murphy et al. 1962).

The aetiology is unknown. Barnett et al. (1961) hold that the disease is due to reactivation of residual embryonal cells, while others claim that it could be a benign neoplasm (Jones 1924, Jaffe 1958, McIvor & King 1962). Our material gives no opportunity to reach conclusions about aetiology, but neither trauma nor infection were reported on in the notes. It seems reasonable to consider the condition to be a benign neoplasm. There are differences of opinion concerning the diagnostic criteria. Mussey & Henderson (1949) made a positive diagnosis even if the synovial membrane was not active at the time of operation provided they found four or more free bodies in the joint. Murphy et al. (1962), McIvor & King (1962) and Paul & Leach (1970) insist on involvement of the synovial membrane while Jaffe (1958) demands that there should be a histological proof of activity in the cartilaginous foci. The diagnosis can possibly be established on an X-ray if there are several free bodies and periarticular calcification. Multiple free bodies but without periarticular calcification can be seen in osteochondritis dissecans, neurotrophical arthopathies and degenerative arthritis. Jaffe (1958) holds that the diagnosis is inconclusive if on X-ray there are multiple free bodies and possible irregularities of the joint, or alternatively one or more defects in the bone. Bone destructions may still occur as shown by McIvor & King (1962) and Bloom & Pattinson (1951) who held bone defects localized in the neck of the femur to be

characteristic of synovial chondromatosis localized in the joint If the X-ray is normal, as it was in six cases in the group operated on in our report, the diagnosis can be difficult, because of the often uncharacteristic symptoms and physical findings

The disease is selflimiting because the metaplastic activity ceases McIvor & King (1962) contend that no treatment except total synovectomy could possibly lead to a cure if this were not true

The small number of cases in our report excludes the possibility of comparing the results in the group where synovectomy was performed with the group where only simple removal of free bodies was carried out Simple removal of free bodies can be curative as confirmed by Jeffreys (1967) Murphy et al (1962) and Jaffe (1958) found synovectomy desirable, but the operation is often difficult to perform—for example, in the hip joint

Murphy et al (1962) point to one case and McIvor et al (1962) to four cases where total synovectomy was attempted after luxation of the hip joint In this material luxation of the hip was performed in one case and an extensive, but partial synovectomy was carried out As a rule there is no indication for this traumatic manoeuvre, as there is a risk of necrosis of the femoral head Generally one can advise removal of all free bodies and excision of that part of the synovial membrane which is accessible

## SUMMARY

A report is given of 22 patients suffering from synovial chondromatosis Sixteen patients were operated on The aetiology and diagnostic criteria are discussed with regard to the literature The X-ray may be characteristic or may alternatively be normal The symptoms and the physical signs are outlined If an indication for treatment is found, removal of all free bodies and excision of the accessible part of the synovial membrane is advised

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*Key words* : chondromatosis capsularis synovial chondromatosis synovial osteochondromatosis , synovial chondrometaplasia loose body formation osteochondromatosis

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Acta orthop scand 46, 926-930, 1975

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# SYNOVIAL CHONDROMATOSIS OF THE METACARPOPHALANGEAL JOINT

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Accepted 10 v 75

Synovial chondromatosis is extremely rare in the small joints (Lewis *& Marshall 1974). In the case reported here, a metacarpophalangeal* localization of synovial chondromatosis was found

## CASE REPORT

A 48-year-old woman presented with a 6-month history of a slowly growing tumour at the fourth metacarpophalangeal joint of her left hand There had not been any trauma in connection with appearance of the tumour and pain

At the examination a plum-sized, mobile tumour was found in the dorsal region and two smaller ones in the palmar region of the joint The roentgenogram of the left hand revealed an erosion of the cortical layer of the fourth metacarpal bone at the distal portion *(Figure 1)* At the operation, the tumour was exposed in the dorsal region Under *the skin the tumour was covered with the thin layer of the joint capsule (Figure 2) The articular cartilage seemed to be intact at the phalangeal as well as the metacarpal sides*

At the macroscopic examination the bisected tumour showed a large solid cartilaginous body and some smaller ones attached to the synovial membrane by thin pedicles Low power light microscopy revealed several nodules within the synovial layer, some of which were free in the joint cavity (Figure 3) At higher magnification the tumour could be characterized as cartilaginous tissue without any sign of malignant transformation (Figure 3, inset) All of the cartilaginous nodules were uncalcified and unossified

*Figure 1 The roentgenogram illustrates a destructive lesion in the distal portion of the fourth metacarpal bone (arrow)*

## DISCUSSION

According to Lewis's review (Lewis & Marshall 1974), only six cases of synovial chondromatosis localized in the small joints of the hand have been reported in the literature. The present report was undertaken partly because of the marked rarity of this disease and partly because of the detailed microscopic examination we could carry out. In making the differential diagnosis osteochondritis dissecans, osteoarthritis, osteochondral fracture, neuropathic joint and rheumatoid arthritis had been excluded.

The light microscope showed different sized cartilaginous nodules localized in the hole of an enlarged synovial cavity. At the same time, smaller islands of cartilaginous tissue could also be found inside the synovial layers. This appearance of the tumour suggests that the cartilaginous bodies could originate from deeper parts of the synovial layer. When the tumour grows the nodules will be extruded more and more into the hole of the joint cavity. The enlarged cartilaginous bodies are attached to the synovial membrane only by thin pedicles or might be

*Figure 2 Gross photograph taken at the time of surgery shows the tumour in the dorsal region of the hand The tip of the pointer is inserted into the joint cavity*

completely free inside the cavity *From the light* microscope pictures we *could see* the steps in development of the nodules, and the multifocal localization of the small cartilaginous cell-groups within the synovial membrane supports the hypothesis *of a multifocal metaplasia* as the *aetiological factor* of the synovial chondromatosis (Aegerter & Kirkpatrick 1968, Jaffe 1968, Jeffreys 1967, Lewis & Marshall 1974, Salter *1970) Naturally, the cause of the metaplasia* is *still unknown (Anderson 1966)*

The synovial chondromatosis can produce articular damage, so surgical treatment is always recommended (Geschickter & Copeland 1949, Jeffreys 1967, Salter 1970, *Silver & Simon 1971, Sprjut et al 1970)* At the operation, removal of the free bodies as well as partial synovectomy also should be performed because of the danger of recidivation and malignant transformation of *the synovial* chondromatosis (Geschickter & Copeland 1949, Jaffe 1968, Lichtenstein 1965)

In the case reported here the operation was successful in respect of function of the hand and relief of the pain No recidivation has developed during 2 years since the operation

*Figure 3 The low power microphotogram demonstrates several nodules in the cavity (pointer) and in the layers (arrows) of synovium. Toluidine blue staining (× 6). The inset corresponds to the region indicated by a rectangle and shows an island of irregularly arranged swollen chondrocytes (× 250)*


## SUMMARY

The authors present a case of synovial chondromatosis localized on the left hand of a woman and discuss the pathogenesis, histology and treatment of the synovial chondromatosis. The patient has been free of complaints for the 2 years since the operation.


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*Key words* chondromatosis, synovial cartilage metacarpal joint synovectomy

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Acta orthop scand 46 931 933 1975

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# PATELLA CUBITI

## *Report of an Operated Case*

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Accepted 26 v 75

Patella cubiti is a rare condition Only occasional cases have been published and as far as we know none from Scandinavia

### CASE REPORT

A 45 year old farm labourer sought medical advice because of in capacitating pain in his right elbow As long as he could remember he had never been able to extend his right elbow fully There was no history of a trauma According to the patient his parents brothers sisters and cousins had normal elbows

Examination of the right elbow revealed some tenderness to palpa tion around the olecranon an extension defect of 35°, 130° flexion and full pronation and supination Also extension against resistance and forced flexion were somewhat painful The roentgenographic appear ance of the elbow is illustrated in Figure 1

The left elbow was normal

A period of rest did not produce the desired result and it was reluctantly decided to extirpate the bone fragment After the fragment was removed from the triceps tendon the elbow was immobilized in plaster for 17 days followed by active exercises Two months after operation the patient returned to work

At review 2 years after the operation the patient was still working full time at the same job He was *quite* satisfied with his elbow and thought that its mobility had increased slightly after the operation Examination revealed that the extension defect had decreased by 5° and flexion had increased by 10° since the operation Pronation and supination were still full and equal on both sides Extension against resistance was good and painless The roentgenographic appearance is shown in Figure 2

*Figure 1 Right elbow, lateral view Typical appearance of patella cubiti*

*Figure 2 Right elbow lateral view 2 years after extirpation of the patella cubiti*

COMMENT

It is still debatable whether patella cubiti is congenital or of traumatic origin (Kienbock 1903, 1914, Gunn 1927, Rostock 1933, Zeitlin 1935, Habbe 1942, Gunn 1965, Mackenzie & Pugh 1972) At least in the present case the condition appeared to be congenital

Few operated cases have been published (Rostock 1931, 1933, Levine 1950, Mackenzie & Pugh 1972) In the present case removal of the bone

fragment eliminated the pain and enabled the patient to return to his work as a farm labourer


## SUMMARY

A case of incapacitating patella cubiti, probably of congenital origin, in a 45 year old farm labourer is described The fragment was extirpated, the pain disappeared and the patient returned to work


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*Key words* patella cubiti operative treatment



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Acta orthop scand 46, 934–948, 1975

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# LUNG VOLUMES IN SCOLIOSIS BEFORE AND AFTER CORRECTION BY THE HARRINGTON INSTRUMENTATION METHOD

MARGARETA LINDH & JAN BJURE

Accepted 10 v 75

The deleterious effect of structural scoliosis on lung volumes is well documented A general survey of the influence of spinal deformities on cardiorespiratory function was reported by Bergofsky et al (1959) and has been pointed out by, among others, Caro & DuBois (1961), Mankin et al (1964), deCoster & Remacle (1967), Westgate (1967), Barois et al (1972), Zorab (1973) and Bjure & Nachemson (1973) The reduction in lung volumes occurs at an early stage of the deformity and this reduction becomes more evident with the more severe curve Since a severe spinal deformity is associated with cardiopulmonary symptoms and often failure, early diagnosis and treatment of scoliosis are imperative

Reports of surgical techniques in the correction of scoliosis have often included their effects on lung function, but the results from this point of view are varying

The purpose of this study is to evaluate, at the completion of treatment, the effect of Harrington instrumentation and fusion on lung volumes in scoliosis patients

## MATERIAL AND METHODS

### *Surgical procedure*

The operative correction of the scoliosis was done with Harrington s distraction rod followed by spinal fusion with autogenous iliac bone In the majority of patients correction was done in two stages with an interval of 2 weeks between operations During this period the patient was kept supine in bed without external

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This study was supported by grants from the Swedish National Association against Heart and Chest Diseases

support The second or fusion procedure was also followed by absolute recumbency for several weeks At this second operation an average of 6 degrees of further correction of the scoliosis was achieved with the Harrington rod (Nordwall 1973) The patient was then allowed out of bed, fitted with a Milwaukee brace and could leave the hospital within a week. After 6 to 7 months of wearing a brace continuously, gradual weaning from the brace was carried out for another 6 to 9 months Gradually increased activities were allowed until 18 months after surgery when the patients had no further restrictions placed on them

*Breathing program*

During the stay at the hospital the patient underwent a breathing program consisting of either conventional breathing exercises or the IPPB (intermittent positive pressure breathing)

Blowing up a balloon of 2- to 4-litre capacity was performed for unsupervised breathing training in both groups

A *Conventional breathing exercises*

1 Deep breathing exercises with diaphragmatic upper costal and lower costal breathing for general ventilation and expansion of the rib cage
2 Resistance added to the lower costal breathing for further expansion of the thorax

B *IPPB*

The Bird respirator was used for intermittent positive pressure breathing to obtain deep inspiration with expansion of the chest

The two methods seemed to have the same effect but the IPPB method has become the routine in training as it is the easiest for both the patient and the therapist

*Subjects*

The study is based on measurements in 92 *consecutive* patients with scoliosis treated as above from 1967 to 1971 87 patients had idiopathic scoliosis and five had paralytic scoliosis due to poliomyelitis There were 83 females and nine males aged 10 to 25 years (Table 1) Seventy seven patients had *dorsal* curves, two had lumbar curves and 13 were operated for double *major curves* The site and pre operative degree of the curves and the degree at follow up are also shown in Table 1 Cobb s method was used to measure the angle of the curves

*Lung volumes* Vital capacity total lung capacity [illegible] ... [illegible] ...tients with paralytic scoliosis (Table 1) Vital capacity was measured in the sitting position using a Bernstein *spirometer*, and functional residual capacity was measured with the helium dilution technique

*Prediction of normal values* For this purpose a corrected height has been used The diminished standing height in scoliosis patients makes it necessary to com

pensate for the height loss when predicting normal values for lung volumes to make possible a comparison between pre- and postoperative measurements.

*Table 1. Physical characteristics of the patients before and after surgery*

| | Idiopathic scoliosis 87 patients (M=7, F=80) | | | | Paralytic scoliosis 5 patients (M=2, F=3) | | | |
|---|---|---|---|---|---|---|---|---|
| | Dorsal curve 73 | | | | Dorsal curve 4 | | | |
| | Lumbar curve 2 | | | | Lumbar curve – | | | |
| | Double major curve 12 | | | | Double major curve 1 | | | |
| | Before surgery | | After surgery | | Before surgery | | After surgery | |
| | mean | s.d. | mean | s.d. | mean | s.d. | mean | s.d. |
| Age (years) | 15.6 | | | | 14.4 | | | |
| Height (cm) | 159.4 | 9.1 | 165.3 | 7.8 | 153.1 | 17.8 | 163.5 | 10.6 |
| Height correction (cm) | 5.1 | 2.7 | 2.1 | 1.5 | 10.1 | 5.0 | 4.5 | 2.2 |
| Corrected height (cm) | 164.4 | 9.1 | 167.4 | 7.9 | 163.2 | 18.3 | 168.0 | 12.1 |
| Degree of scoliosis | 72 | | 38 | | 99 | | 67 | |
| Follow up time (range 1.5–5.0) years | | | 2.9 | | | | 3.5 | |

Using spine roentgenograms the *height reduction was quantitated by determining* the difference in length of a wire superimposed on the actual roentgenographic curve as compared with actual vertical height of the spine (Bjure et al. 1968). The possible influence of kyphosis and lordosis was not taken into consideration but has been discussed since then by Bjure & Nachemson (1973). The logarithm of the *trunk height loss (Y) was linearly correlated to the angulation of the curvature (X)*: Log Y = 0.011 X – 0.177 (in the original paper the regression equation for this relation was given with an erroneous sign). For the 13 patients with double major scoliosis both curves have been taken into consideration. The method is good in curves below 100° but above this figure we overestimate the height loss and this *error increases with increasing curvature*. *The reason for this* might be that the regression line calculated from the logarithmic equation did not fit the individual values at the end of the curve. The original presentation of the method was based on 62 patients in whom most of the curves were below 100°. To make a more accurate correction of height loss in patients with severe curves we have added another 13 patients with severe curves to the original number of 62 making a total number of 75 patients. A line is fitted by hand to the individual values of the relation between angulation of the curvature and trunk height loss. In this paper we have used the correction factors for different curvatures above 100° taken from that relation and given in Figure 1 together with curves also below 100°. A table of the correction factor in centimetres for a given curvature is included in the figure. For practical use, however, the decimal has been rounded off to the closest 0.5.

*Analysis of data.* Measurements of vital capacity were made in all patients but functional residual capacity and residual volume were not available in all cases. The results are presented in two ways: 1. In absolute values in litres, 2. In per cent

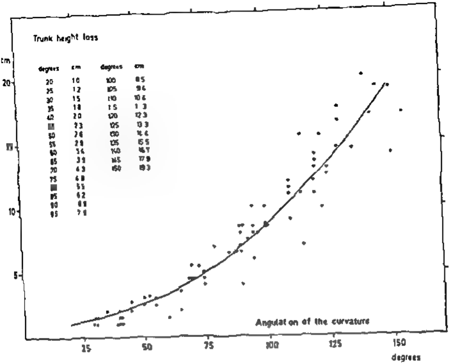


*Figure 1* Correction factors in cm according to the degree of scoliosis

of predicted normal values where the predictions are based on age and the corrected height using the correction factor presented above The normal values were predicted according to the formulae given by Berglund et al (1963) Grimby & Söderholm (1963) and for patients below 18 years of age according to the formula of Bjure 1963) for vital capacity and according to Helliesen et al (1958) for other lung volumes

To evaluate further the effect of the Harrington procedure of lung volumes the idiopathic group was divided into three groups according to the preoperative curve in order to discover if any possible correlation exists between changes in lung volumes after surgery and preoperative degree of curvature Double major curves were classified with the thoracic curves The three groups comprise patients with curves less than 60 degrees from 60–89 degrees and more than 89 degrees (Table 2)

## RESULTS

*Effect of surgery on the curvature* The correction of the curvature by the Harrington procedure is seen in Table 1 for both idiopathic and paralytic scoliosis The postoperative curves measured at follow-up show a reduction of 50 and 35 per cent respectively The reduction with

pensate for the height loss when predicting normal values for lung volumes to make possible a comparison between pre- and postoperative measurements.

*Table 1. Physical characteristics of the patients before and after surgery*

| | Idiopathic scoliosis 87 patients (M=7, F=80) | | | | Paralytic scoliosis 5 patients (M=2, F=3) | | | |
|---|---|---|---|---|---|---|---|---|
| | Dorsal curve 73 | | | | Dorsal curve 4 | | | |
| | Lumbar curve [illegible] | | | | Lumbar curve – | | | |
| | Double major curve 12 | | | | Double major curve 1 | | | |
| | Before surgery | | After surgery | | Before surgery | | After surgery | |
| | mean | s.d. | mean | s.d. | mean | s.d. | mean | s.d. |
| Age (years) | 15.6 | | | | 14.4 | | | |
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| Height correction (cm) | 5.1 | 2.7 | 2.1 | 1.5 | 10.1 | 5.0 | 4.5 | 2.2 |
| Corrected height (cm) | 164.4 | 9.1 | 167.4 | 7.9 | 163.2 | 18.3 | 168.0 | 12.1 |
| Degree of scoliosis | 72 | | 38 | | 99 | | 67 | |
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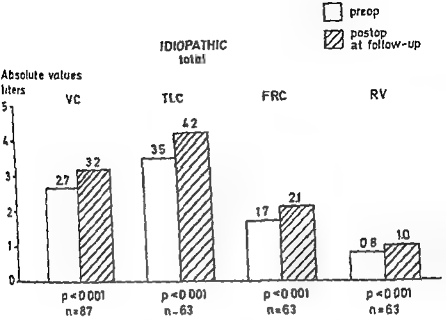


*Figure 2 Lung volumes in litres pre and postoperatively Idiopathic scoliosis*

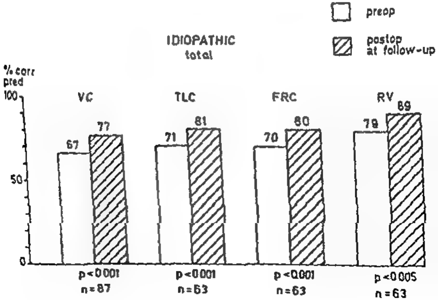


*Figure 3 Lung volumes in per cent of predicted normal values pre and post operatively Idiopathic scoliosis*

*Table 2 Characteristics of the patients with idiopathic scoliosis according to the degree of the curvature*

| | < 60 ° 22 patients | | | | 60–89 ° 49 patients | | | | > 89 ° 16 patients | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Before surgery | | After surgery | | Before surgery | | After surgery | | Before surgery | | After surgery | |
| | mean | s d | mean | s d | mean | s d | mean | s d | mean | s d | mean | s d |
| Age (years) | 14 4 | | | | 15 8 | | | | 16 8 | | | |
| Height (cm) | 160 4 | 5 1 | 165 7 | 4 | 159 8 | 10 5 | 165 3 | 9 3 | 156 7 | 9 0 | 164 6 | 7 1 |
| Height correction (cm) | 2 8 | 0 8 | 1 4 | 0 6 | 4 8 | 1 7 | 1 9 | 1 0 | 9 0 | 3 0 | 3 5 | 2 6 |
| Corrected height (cm) | 163 2 | 4 9 | 167 1 | 4 1 | 164 6 | 10 2 | 167 2 | 9 3 | 165 7 | 10 1 | 168 2 | 7 4 |
| Degree of scoliosis | 52 | | 27 | | 72 | | 36 | | 103 | | 59 | |
| Follow-up time (years) | | | 3 | | | | 2 6 | | | | 3 2 | |

*Table 3 Statistical results of the measurements of pulmonary function in the patients with idiopathic scoliosis*

| | Before surgery | | After surgery | | $p$ |
|---|---|---|---|---|---|
| | mean | s d | mean | s d | |
| VC in litres | 2 7 | 0 64 | 3 2 | 0 59 | < 0 001 |
| VC in % normal "corrected" | 67 | 14 5 | 77 | 12 4 | < 0 001 |
| TLC in litres | 3 5 | 0 73 | 4 2 | 0 68 | < 0 001 |
| TLC in % normal "corrected" | 71 | 12 7 | 81 | 10 7 | < 0 001 |
| FRC in litres | 1 7 | 0 41 | 2 1 | 0 48 | < 0 001 |
| FRC in % normal "corrected" | 70 | 13 6 | 80 | 14 5 | < 0 001 |
| RV in litres | 0 8 | 0 27 | 1 0 | 0 33 | < 0 001 |
| RV in % normal "corrected" | 79 | 24 8 | 89 | 26 6 | < 0 005 |

VC = vital capacity
TLC = total lung capacity
FRC = functional residual capacity
RV = residual volume

respect to the preoperative angle of the curve is shown in Table 2 for idiopathic scoliosis, in which the severe group is to be compared with the paralytic group in Table 1

The difference in corrected height before and after operation (Tables 1 and 2) gives a measure of the actual growth up to the time of follow-up. The mean correction factor for the idiopathic group all together (Table 1) was 5 1 cm before surgery and 2 1 cm after surgery The cor-

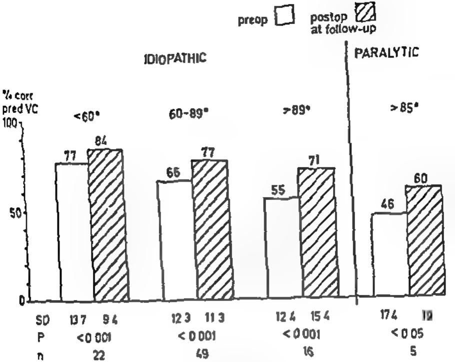


*Figure 5 Vital capacity in per cent of predicted normal values pre and post operatively according to the preoperative degree of scoliosis Idiopathic and paralytic scoliosis*

capacity, functional residual capacity and residual volume averaging 0.5 0.7 0.4 and 0.2 litres respectively Figure 3 gives the result in per cent of corrected predicted normal values For all volumes there was an increase of 10 per cent, which is highly significant

When dividing the idiopathic group into three groups according to the preoperative degree of the curvature, the increase in litres for vital capacity was 0.5 litres for curves less than 60 degrees, 0.5 for curves 60 to 89 degrees and 0.8 litres for the more severe group with curves above 89 degrees The last group can be compared with the severe paralytic group with a curve of more than 85 degrees, showing an increase of 0.6 litres (Figure 4) Figure 5 shows the increase in per cent of corrected predicted normal values For the idiopathic subgroups the increase was 7 11 and 16 per cent respectively and the paralytic group showed an increase of 14 per cent, all changes in volumes being highly significant

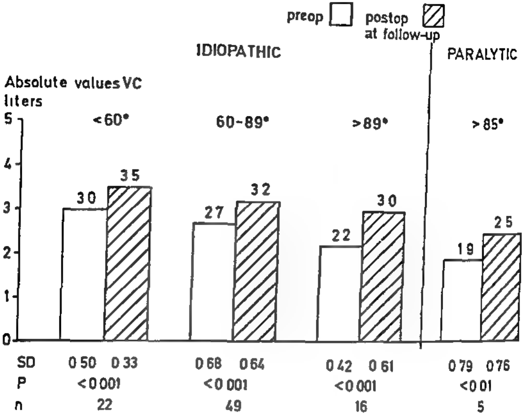


*Figure 4* *Vital capacity in litres pre and postoperatively according to the preoperative degree of scoliosis Idiopathic and paralytic scoliosis*

rected height averaged 164.4 cm and 167.4 cm respectively According to the degree of the preoperative curvature (Table 2), the correction factor for idiopathic scoliosis less than 60 degrees was 2.8 cm before surgery and 1.4 cm after surgery, for the group of 60 to 89 degrees 4.8 cm and 1.9 cm, for more than 89 degrees 0 cm and 3.5 cm The latter is to be compared with the severe paralytic group of 10.1 cm and 4.5 cm respectively (Table 1)

*Effect of surgery on lung volume* The results are shown in absolute values in litres as well as in per cent of predicted normal values Absolute values in litres alone will not give an accurate result of the effect of the surgery itself, since they do not take into account the natural increase in volumes due to growth A comparison of predicted normal values according to corrected height gives a better evaluation of the operation procedure itself, excluding the growth factor Figure [illegible] gives the result for the total idiopathic group in absolute values in litres There were significant increases in vital capacity, total lung

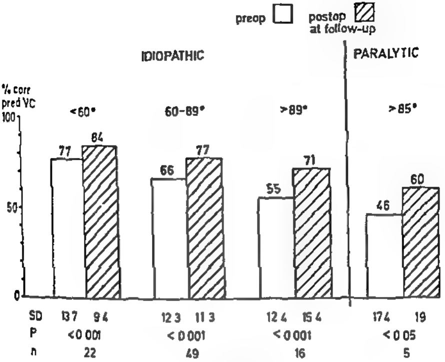


*Figure 5 Vital capacity in per cent of predicted normal values pre- and post-operatively according to the preoperative degree of scoliosis, Idiopathic and paralytic scoliosis*

capacity, functional residual capacity and residual volume averaging 0 5 0 7, 0 4 and 0 2 litres respectively Figure 3 gives the result in per cent of corrected predicted normal values For all volumes there was an increase of 10 per cent, which is highly significant

When dividing the idiopathic group into three groups according to the preoperative degree of the curvature, the increase in litres for vital capacity was 0 5 litres for curves less than 60 degrees, 0 5 for curves 60 to 89 degrees and 0 8 litres for the more severe group with curves above 89 degrees The last group can be compared with the severe paralytic group with a curve of more than 85 degrees, showing an increase of 0 6 litres (Figure 4) Figure 5 shows the increase in per cent of corrected predicted normal values For the idiopathic subgroups the increase was 7, 11 and 16 per cent respectively and the paralytic group showed an increase of 14 per cent, all changes in volumes being highly significant

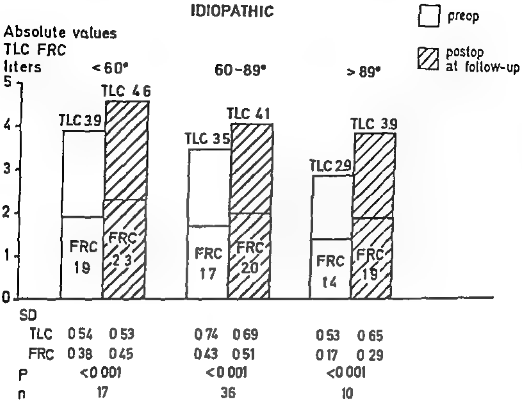


*Figure 6 Total lung capacity and functional residual capacity in litres pre- and postoperatively according to the preoperative degree of scoliosis Idiopathic scoliosis*

Absolute values for total lung capacity in the different subgroups of idiopathic scoliosis showed an increase of 0 7, 0 6 and 1 0 litres respectively (Figure 6) The increase of functional residual capacity in the same groups was 0 4, 0 3 and 0 5 litres Figure 7 gives the data in per cent predicted to corrected height For total lung capacity there were increases of 8, [illegible] and 16 per cent respectively, and for functional residual capacity the increases were 12, 7 and 18 per cent respectively, all increases being highly significant Table 3 gives the results for the idiopathic group in total The increase in residual volume was significant when counted up in a large number of patients In smaller groups, however, the increase became less or not significant

Thus for the idiopathic group an average 10 per cent increase in vital capacity, total lung capacity and functional residual capacity was obtained after surgery When this increase was correlated with the preoperative angle of scoliosis, the increase turned out to be most obvious in the severe cases of scoliosis

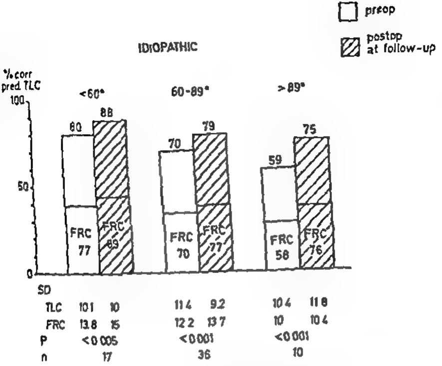


*Figure 7 Total lung capacity and functional residual capacity in per cent of predicted normal values pre and postoperatively according to the preoperative degree of scoliosis Idiopathic scoliosis*

## DISCUSSION

Scoliosis causes reduction in lung volumes and the degree of the reduction varies with the severity of the curve The paralytic subgroup is small but illustrates that with involvement of the respiratory muscles the reduction in lung volumes is more marked than one would expect for idiopathic scoliosis of the same degree of severity

When comparing lung function in scoliosis patients with lung function in normal persons it is important to take into consideration the loss of height due to the spinal deformity Various parameters have been used in predicting normal values for lung volumes in patients with scoliosis (Zorab & Prime 1963 Hepper et al 1965 Vallbona et al 1962 Johnson & Westgate 1970) The method described by Bjure et al (1968) with its modification is an easy way of correcting height for scoliosis and is valid in practice The correction of height makes it

possible to compare pre and postoperative values without influence of the natural increase in lung volumes due to growth

One would expect excluding any possible defects in the lung tissue that a *correction of the spinal curvature would increase the thoracic* cavity improve the rib movements on the concave side and thus make an increase of lung volumes possible Cotrel (1965) found an improvement in vital capacity of 30 40 per cent with the EDF (Elongation Derotation Flexion) method and fusion but this improvement was not calculated with a corrected height Maklev et al (1968) demonstrated no significant improvement of pulmonary function following spine fusion The *application of a preoperative corrective device* reduced lung volumes except when the halo apparatus was used Cook et al (1960) and Gucker (1962) had similar experiences and even showed a tendency for further decrease in lung volumes after fusion

Previous reports of the actual effect of the posterior fusion with the Harrington instrumentation on *lung volume have shown various* results Gazioglu et al (1968) obtained a gain of 17 per cent in vital capacity for idiopathic scoliosis 1 year after surgery A follow up several years later did not change the results The preoperative degree of the curvature did not influence the result Predictions of normal values for vital capacity were made from measurements of arm span in normals Meznik et al (1972) showed in the majority of cases a mean *increase of about 10 per cent with no information* of the way of predicting lung volumes to normal Westgate & Moe (1969) found a decrease in vital capacity 1 year after surgery as well as 5 years postoperatively The preoperative height of the patient was used when predicting normal values of lung volumes Meister & Heine (1973) reported no *change in vital capacity 1 year after surgery and his predictions* of vital capacity were calculated from pre and postoperative heights Vallbona et al (1969) used a corrected height for predicting vital capacity and reported no significant change in lung volumes 1 year after surgery Henche et al (1971) using predicted height showed a decrease in vital capacity *1 year after surgery for both idiopathic and paralytic* scoliosis A 2 year control however showed a 12 per cent increase in vital capacity for the idiopathic group but for the paralytic scoliosis there was still a decrease compared to preoperative values

This study showed an average increase of 10 per cent in idiopathic scoliosis that was *highly significant There was an obvious* trend for patients with the worst curves before surgery to have the better lung function results after surgery The increase in lung volumes was highly

significant even in the paralytic group, but this group is too small for further discussion

Since the time of follow up varied from 18 months to [illegible] years, we looked for any differences between the groups of patients followed for less than 2 years and the group followed for more than 2 years after surgery Postoperative development of vital capacity related to average age at operation was also evaluated There was a trend for better results the longer the time of follow-up and the younger the patient, i e younger than 16 years of age Statistically, however, the variations were not significant

As the results concerning changes in lung volumes after the Harrington operation technique for scoliosis vary with reports of deterioration as well as of improvement of lung volumes the pre- and postoperative treatment routine may be of importance for the result Lindh & Nachemson (1970) showed that breathing exercises are important for obtaining quicker return to preoperative vital capacities after the decrease that occurs immediately after surgery That study further showed that, 6 weeks after surgery, the average increase in vital capacity for a trained group of patients was 12 per cent compared to 3–4 per cent for an untrained group However, this difference decreased gradually and in this long term follow up the difference was no longer significant For early improvement in lung function, breathing treatment is routinely given with the IPPB method recently described by Sinha & Bergofsky (1972)

The most important part in the postoperative routine for the early recovery of the lung function is probably that no external support of plaster body jackets is used restricting the chest expansion The patient is mobilized using a Milwaukee brace which makes it possible for the patient to breathe deeply and expand the chest fully, which is not possible to the same extent in a plaster of Paris Makley et al (1968) among others noticed the negative effects of the Risser cast in this respect Experimental studies of the effects of restriction of chest cage expansion on pulmonary function are described by Caro et al (1960) and show the importance of satisfactory chest expansion for pulmonary function The Milwaukee brace in the postoperative treatment f[illegible]

used [illegible]

the b[illegible] measured in the brace will not differ much from a test without the brace

## SUMMARY

Studies of static lung volumes were performed before and after surgery in 92 scoliotic patients, aged 10 to 25 years The majority of the patients had idiopathic dorsal curves Vital capacity, total lung capacity, functional residual capacity and residual volume were measured at least 18 months after surgery A significant increase was observed in all static volumes, averaging 10 per cent, the pre- and postoperative values were expressed in per cent of predicted normal values according to age and height Correction of body height was taken into consideration in the prediction of normal values Patients with the more advanced scoliosis had the greatest improvement in lung volumes The patients were treated postoperatively with a Milwaukee brace for an average of 15 months The use of this brace, which allows for chest expansion, might account for the improved lung function compared to previous series where plaster body jackets were used

Thus the correction of idiopathic scoliosis by the standard posterior fusion with Harrington instrumentation together with our postoperative routine provides a lasting reduction of the spinal deformity, prevents progression of respiratory impairment and, in fact, increases the lung volumes, vital capacity, total lung capacity and functional residual capacity by an average of 10 per cent


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Studies of static lung volumes were performed before and after surgery in 92 scoliotic patients, aged 10 to 25 years The majority of the patients had idiopathic dorsal curves Vital capacity, total lung capacity, functional residual capacity and residual volume were measured at least 18 months after surgery A significant increase was observed in all static volumes, averaging 10 per cent, the pre- and postoperative values were expressed in per cent of predicted normal values according to age and height Correction of body height was taken into consideration in the prediction of normal values Patients with the more advanced scoliosis had the greatest improvement in lung volumes The patients were treated postoperatively with a Milwaukee brace for an average of 15 months The use of this brace, which allows for chest expansion, might account for the improved lung function compared to previous series where plaster body jackets were used

Thus the correction of idiopathic scoliosis by the standard posterior fusion with Harrington instrumentation together with our postoperative routine provides a lasting reduction of the spinal deformity, *prevents progression of respiratory impairment and, in fact, increases* the lung volumes, vital capacity, total lung capacity and functional residual capacity by an average of 10 per cent


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Acta orthop scand 46 949 956 1975

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# THREE-DIMENSIONAL OBSERVATION OF COLLAGEN FRAMEWORK OF LUMBAR INTERVERTEBRAL DISCS

HAJIME INOUE & TETSUAKI TAKEDA

Accepted 30 vi 75

The anatomy and pathology of the intervertebral discs have seldom been described The arrangement of the collagen fibers has recently been examined using light microscopy (Saunders & Inman 1940, Coventory et al 1945, Hirsch & Schajowitz 1952, DePalma & Rothman 1970) X ray crystallographic techniques (Horton 1958) and electron microscopy (Sylvén et al 1951, Happey et al 1964 Gomibuchi 1964) However no complete demonstration is found of the three dimensional architecture of the intervertebral discs at the ultrastructural level In the present study scanning electron microscopy (SEM) was used to examine the fibrous framework of the discs

## MATERIALS AND METHODS

The lumbar intervertebral discs with the connected vertebral bodies were obtained from Wistar rats adult hybrid dogs and from humans of various ages The freshly removed discs were washed with physiological saline and divided into two parts on the vertical and the horizontal planes using a sharp razor Specimens for SEM were prepared by two methods half of the specimen was immersed in 2 5 per cent glutaraldehyde and postfixed in 1 per cent osmium tetroxide and the other half of the specimen was immersed for 2 3 hours in chymotrypsin solution washed with phosphate buffer and fixed similarly The samples were dried by the critical point meth d evaporated with goldpalladium and examined by L 3 SEM (JEOL Ltd. and field emission type SEM Hitachi Ltd ) Samples from the same source as used in SEM investigation were examined by polarized light microscopy

## RESULTS

### *Intervertebral discs of rats*

The horizontally cut surfaces of the rat lumbar discs showed the concentric structure of the lamellae of annulus fibrosus The lamellae in

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*Key words* lung volumes, scoliosis, operation

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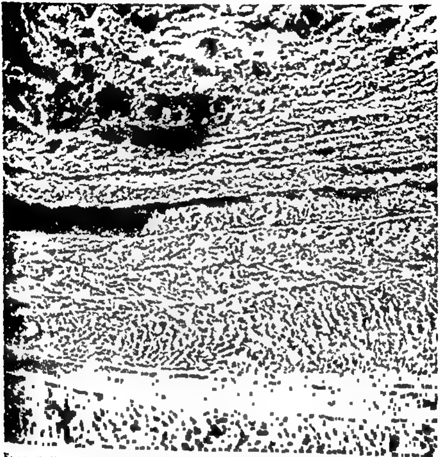

*Figure 2 Horizontally cut surface of a dog disc showing transitional area of the nucleus pulposus and the annulus fibrosus × 120*

fibers in successive layers were interwoven with alternate lamellae (Figure 1)

*Intervertebral discs of dogs*

In horizontally cut surfaces of discs from dogs, irregular nets of fine fibrils of the nucleus usually overlapped one another forming a thin membraneous structure These collagen fibrils in the nucleus pulposus gradually entered into the lamellar structure of the annulus fibrosus, and the thickness of the lamellae increased from the inner to the outer layers (Figure 2) In the middle layer of the annulus, the individual

*Figure 1.* *Three-dimensional framework of the fibrous bundles forming the annulus fibrosus of a rat. The bundles forming each lamella successively cross and run obliquely to the vertebral bodies above and below.* × 1[illegible]0

the anterior areas measured approximately 20 μ in thickness, while the lamellae were thinner in the posterior areas. Each lamella contained numerous fine fibrils 0.1–0.2 μ in diameter which were lined in an uniform direction. Observations of specimens whose cut surfaces were peeled and separated allowed a clear view of the architecture. The concentric lamellae appeared in neat layers. Each lamella was split into regularly arranged fibrillar bundles of about 10 μ in diameter. The fibers of the lamellae ran obliquely from one vertebra to the next. The

*Figure 3 Field emission SEM picture clearly showing the regular orientation of collagen fibrils in the annulus which have been mostly denuded by chymotrypsin treatment × 31 000*

off after treatment with chymotrypsin The collagen fibrils were 0 1 0 2 μ in diameter with a regular periodicity of about 600 Å in width Granular particles of the remaining MPSP were seen on the separated fibrils (Figure 4) Stereoscopic views of vertically cut surfaces indicated that the slant fibrillar lamellae of the annulus adjacent to the nucleus entered into the cartilage plate However, no connection of fibrils was found between the nucleus and the cartilage plate The cartilage plate was made of a close network of fibrils running parallel to the vertebral bodies

## DISCUSSION

Light microscopic studies of the disc (Saunders & Inman 1940 Coventry et al 1945 Hirsch & Schajowitz 1952 DePalma & Rothman 1970) have drawn attention to its functional properties These studies have suggested that the collagen fibers of one lamella crossing the fibers of the next lamella contribute to the strength and elasticity of the disc However the precise arrangements of the fibrous components of the intervertebral discs were not adequately demonstrated because of methodological limitations Our SEM images of the cut and teased

*Figure 3. High power view of an adult human nucleus demonstrating the collagen framework irregularly aligned. × 1[illegible] 000*

lamellae measured about 50 μ in thickness and were composed of fibrillar bundles.

## *Intervertebral discs of humans*

The fibrillar arrangement of the nucleus in adults showed an irregular network. Most of the fibrils measured 0.1–0.15 μ in diameter and granular particles of 0.05–0.08 μ in size were attached to the fibrillar surfaces (Figure 3). The characteristic periodicity of the banding structure was found on the fibrils. The granular particles probably correspond to the mucopolysaccharide protein (MPSP) complex.

A regular orientation of the annular lamellae was found in the adult human discs with a slight increase in thickness from the inner to the outer lamellae. However, lamellae of the posterior areas of the disc were generally thinner than those of the anterior areas and were partly interwoven with each other. The lamellae of the annulus easily peeled

*Figure 4 Field emission SEM picture clearly showing the regular orientation of collagen fibrils in the annulus which have been mostly denuded by chymotrypsin treatment × 31,000*

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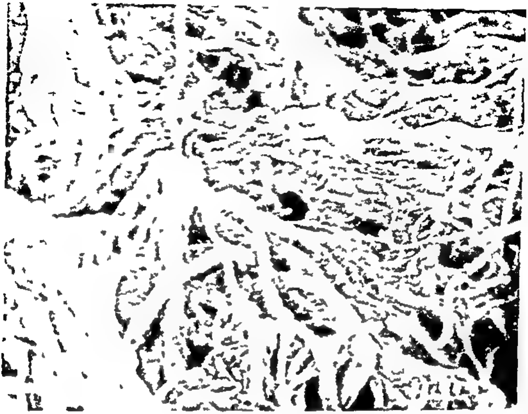

*Figure 3 High power view of an adult human nucleus demonstrating the collagen framework irregularly aligned × 12 000*

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## SUMMARY

Lumbar intervertebral discs obtained from rats, dogs and humans were examined by scanning electron microscopy. The nucleus pulposus was constructed of a loose network of fine fibrils and formed lamellated membranes in the peripheral areas. The annulus fibrosus was composed of concentric lamellae of fibrous bundles that ran uniformly in each lamella and crossed over to the bundles of adjoining lamellae. The lamellae were made of fine fibrils measuring 0.1–0.2 μ in diameter, corresponding to matured collagen fibrils. The cartilage plate consisted of a close meshwork of collagen fibrils which interconnected with the annular fibrils. From these results, it was concluded that the intervertebral disc was well developed for shock absorption at the light microscopic and ultrastructural levels. In specimens treated with chymotrypsin, the extra fibrillar substances were easily digested in the nucleus as well as in the annulus. The intervertebral disc may thus be easily affected by chemical agents.

## ACKNOWLEDGEMENT

The authors are greatly indebted to Prof. Toshio Kodama, Director of the Department of Orthopaedic Surgery of our medical school, for his guidance throughout this work and for his critical reading of the manuscript.

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surfaces of the disc allowed examinations of the fibrous architecture of the three different parts of the disc (Inoue 1973, Takeda 1975). Sylven et al. (1951) demonstrated by transmission electron microscopy (TEM) that the collagen fibrils of the nucleus measure 170–1260 Å in diameter and that the periodicity is 560–712 Å in width. The fine fibrils found in the present study showed a larger diameter than the collagen fibrils previously described by TEM (Sylven et al. 1951, Happey et al. 1964, Gomibuchi 1964). This discrepancy in fibrillar diameter may be due to MPSP that are known to cover the fibrillar surfaces in TEM.

The nucleus from young human subjects is gel-like and contains much MPSP and less collagen fibrils (Hirsch et al. 1953). Happey et al. (1964) reported that networks in the nucleus are thinner than those in the annulus. In the present study, it was difficult to find differences of fibrillar thickness between the nucleus and the annulus.

The present SEM examinations also demonstrated that the lamellae in the anterior areas were slightly wider than those in the posterior areas where interlacing arrangements of lamellae were present. It can be inferred that the architecture of the intervertebral disc is fairly different in the anterior and posterior areas of the lamellae but that the fibrillar size of the lamellae does not differ.

Our observations indicate that the fine fibrillar network of the cartilage plate resembles that of the articular cartilages previously investigated by SEM (Clarke 1971, Inoue 1975). This network probably facilitates the flow of metabolities and water from the vertebral bodies to the nucleus by compression and decompression of tissues (Nachemson et al. 1970).

On the other hand, Hirsch & Sonnerup (1968) reported that the shock-absorbing function was based upon hydrodynamic action which probably depends upon hydroscopicity of the MPSP in the nucleus (Macnab 1969). Furthermore, the present study suggests that shock-absorption relates not only to the nucleus but also to the annulus, as the discs are composed of markedly tough fibrillar lamellae that enclose the nucleus (Hirsch & Sonnerup 1968, Macnab 1969). The intervertebral discs are also well-developed in adjusting to shock. Aging and pathological processes may cause degeneration of this three-dimensional architecture.

In the present study, it was found that chymotrypsin easily digests the extra-fibrillar substances and denudes the collagen fibrils. This indicates that the disc can be affected by chemical agents produced by the degenerating discs.

Acta orthop scand 46 957 962 1975

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# VIRAL ANTIBODY TITERS TO RUBELLA IN COXA PLANA OR PERTHES' DISEASE

*Perthes Disease Is it the Late Osseous Residua of a Minor Prenatal Rubella?*

JOHN A MATSOUKAS

Accepted 4 1 75

Coxa plana (CP) still remains as much of an etiologic enigma as when it was first recognized as a clinical entity in the classic descriptions of Legg Perthes and Calve in 1910 Among all osteochondroses CP is undoubtedly the one which is of most interest and has been most studied The frequency of bilateral involvement also suggests a constitutional abnormality (Sharrard 1971)

Among the many suggested etiological agents are trauma infection endocrine inbalance metabolic disturbance and heredity Each of these theoretical possibilities has had its champion at one time or another but none has received general acceptance Figures suggest an incidence in the general population of about 1 per 2000 living All surveys report a preponderance of males the ratio being 4 or 5 males to 1 female CP is unknown in Negroes It has been said that trauma may be a precipitating cause The least genetic reports are compatible with multifactorial inheritance (Wynne Davies 1973) Also the pathogenesis of CP is undetermined Recent experiments support the vascular concept Some authors believe that venous thrombosis is a more likely cause of CP than arterial occlusion Another field of research has been the investigation of the child as a whole rather than his hip in particular (Catterall 1971) It has been known for some years that these children are smaller weigh less at birth and have delayed bone age (Girdany & Osman 1968) I believe that CP reflects an unsettled generalized disturbance of congenital origin rather than a localized disorder of the hip For this reason I have been studying this disease from a completely different viewpoint It is emphasized that the results of the present study support my hypothesis

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*Key words* scanning electron microscopy, collagen framework, intervertebral discs

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*Figure 1 Small artery from the articular vessels of a child with coxa plana Attention is drawn to the eccentric endothelial thickening and to the increase in wall to lumen ratio (Verhoeff's elastic stain X 250)*

serum were used beginning with ¼ dilution and viral antibody titers were expressed as the reciprocal of the highest dilution which completely inhibited hemagglutination of the chicken erythrocytes Analysis of positive sera indicated that (a) persistent rubella HI antibody titers among tested children with CP have been found only in the younger affected children They were much lower than titers seen among those of the same age with postnatally acquired rubella (b) Negative sera correspond to those of control children except for two where there was evidence of a four fold rise in rubella antibody titer, that was indicative of a recent infection (c) HI antibodies persist to detectable levels in all mothers of the affected children Such levels were suggestive of the likelihood that only some years had passed since the probable rubella attack. Although neutralizing and HI antibodies persist for life in the majority of the control mothers positive results

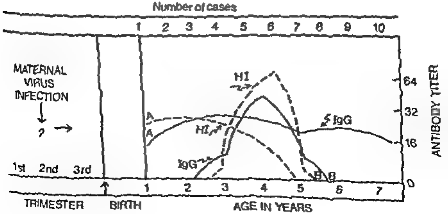


*Figure 2 Diagram illustrating the pattern of antibody response in the two groups of children A affected B controls*

## MATERIALS, METHODS AND RESULTS

The present study is subdivided into three parts The first part includes the research for associated defects in a series of 60 children with CP The second part is connected with research of the pattern of rubella response in 10 pairs of mothers and their affected children Finally, the third part is related to the histologic study of vascular branches of five affected hips

### *Part I*

A careful survey for associated defects revealed the following (Table 1) When examined, in a series of 60 children with CP disease, two of them had epilepsy, one patient had congenital cardiovascular defect Inguinal hernia was present in ten children, of whom one had a severe speech defect, one renal disease and one hypospadias Minor skeletal defects such as spina bifida occulta were present in 17 children, dental abnormalities in five and dermatoglyphic alterations in three Two children also had hypacusia of unknown origin

*Table 1 The various associated defects found in 60 children with coxa plana*

| No | Associated defect(s) | No of cases |
|---|---|---|
| 1 | Epilepsy | 2 |
| 2 | Patent ductus arteriosus | 1 |
| 3 | Renal disease (calcinosis) | 1 |
| 4 | Inguinal hernia | 10 |
| 5 | Hypospadias | 1 |
| 6 | Speech defect | 1 |
| 7 | Spina bifida occulta | 17 |
| 8 | Dental anomalies | 5 |
| 9 | Dermatoglyphic alterations | 3 |
| 10 | Hypacusia | 2 |

### *Part II Testing for rubella*

1 Viral antibody titers were determined by hemagglutination inhibition techniques in microtiter plates Rubella titers were performed acording to the method that no patient has a positive history of natural rubella infection nor was vaccinated by live rubella virus vaccine To be able to compare the results we have used two control groups one of 10 non affected children and one consisting of their mothers All the controls were approximately of the same age and came from the same geographic areas

1 Viral antibody titers were determined by hemagglutination inhibition techniques in microtiter plates Rubella titers were performed according to the method of Stewart Sera were treated with kaolin, adsorbed with erythrocytes from 1 day-old chickens, and heat inactivated at 56° C for 30 minutes prior to testing against four hemagglutination units of rubella virus strain M 33 Two fold dilutions of

the long bones of a considerable number of children with congenital rubella shows irregular mineralization at the areas of ossification and in the metaphyses (Singleton et al 1966) Unusual dermatoglyphics associated with the congenital rubella syndrome were described by Achs & Siegel in 1966 Among Negro women, the absence of neutralizing antibody was significantly greater than among whites (Sever 1964) The fibromuscular changes in our patients' vessels conform to those described in children with congenital rubella Rubella is notorious for the production of proliferative vascular lesions (Esterly & Oppenheimer 1967) If there really is an etiologic relationship then the production of an unsuspicious vasculo-osseous syndrome is explained It is still possible to account fully for the clinical features of CP on the basis of a vasculitis and a biologically inferior bone This vasculopathy which is a constant feature in all the cases examined may cause one of infarction necrosis In addition, a well documented arterial communication between the upper and lower cervical circulation in the female can be the explanation of the differences of incidence of CP in the two sexes

To summarize, all the above data, viz clinical, histological and particularly immunological aspects, indicate the need for a discussion of a probable etiologic correlation between prenatal rubella and CP Despite absence of lesions classically associated with rubella syndrome this osseous disorder may represent a forme fruste of that disease It is very likely that CP is not a localized disorder nor a distinct entity but the late osseous residua or stigma of very mild prenatal viral infection with a sub-clinical course in the mother If that is true, a progressive disappearance of CP is possible in the future

## SUMMARY

The present study seriously raises the question as to whether coxa plana is etiologically connected to the rubella virus Some findings suggests a probable causal correlation between prenatal rubella and coxa plana A regional vasculitis in association with biologically inferior bone probably constitutes the fundamental pathogenetic mechanism of this condition However, this matter is still awaiting elucidation

were not obtained Only three controls had positive sera, but the geometric mean titers of these were much lower than those of the test mothers

2 Neutralizing antibodies, particularly IgG (7S) persist in all the test children and the same antibodies persist to detectable levels in all the test mothers This pattern was in marked contrast to the pattern of both control groups Actively acquired IgG appears to be the dominant rubella antibody in all affected children Among the controls higher levels of antibody were found in only two Half of the control mothers were negative whereas the other half showed minimal levels of IgG

In conclusion, the pattern of antibody response of the patients and their mothers differs significantly from the pattern of the controls The main difference lies in the higher levels of antibodies in all the affected children and in all their mothers

*Part III Histologic study*

Vascular lesions were studied in five children with CP in connection with surgical intervention The vulnerable vascular channels are the cervical branches arising from the cervical circle and which traverse the joint cavity to reach the capital femoral epiphysis Several such cervical branches have been examined The severity of involvement varied No significant lesions were found in arterioles or veins Diffuse proliferation of the arterial intima was the most characteristic lesion in all these cases At some sites the intima was more than twice as thick as the remaining arterial wall The internal elastic lamella and media were almost always unchanged, even in the presence of a greatly thickened intima (Figure 1) Conclusion The characteristic finding was intimal fibromuscular proliferation

## DISCUSSION

The surprising findings of the present study provide some support for the suggestion that CP probably reflects the effect of rubella virus during the prenatal period It is well known that the multiplicity of defects is the striking feature of congenital rubella in children

Virtually every organ may be involved singly, multiply, transiently, or progressively and permanently (Krugman & Ward 1973) It is true also that rubella infections after the 14th week of pregnancy do not result in malformation, but they do endanger the fetus to some extent Overall, manifestations were less severe and more subtle than those of infections during the first trimester (Warkany 1971) Developmental delay was seen in young affected children (Cooper 1968) Renal and ureteric malformations were noted by Gregg (1941) and other workers Hypospadias has been observed repeatedly in boys with congenital rubella There was reports in the past of spina bifida, renal anomalies and hypospadias following maternal rubella that were usually considered coincidental An increased incidence of indirect inguinal hernias has been reported (Hardy & Sever 1968) Roentgenography of

the long bones of a considerable number of children with congenital rubella shows irregular mineralization at the areas of ossification and in the metaphyses (Singleton et al 1966) Unusual dermatoglyphics associated with the congenital rubella syndrome were described by Achs & Siegel in 1966 Among Negro women, the absence of neutralizing antibody was significantly greater than among whites (Sever 1964) The fibromuscular changes in our patients vessels conform to those described in children with congenital rubella Rubella is notorious for the production of proliferative vascular lesions (Esterly & Oppenheimer 1967) If there really is an etiologic relationship then the production of an unsuspicious vasculo osseous syndrome is explained It is still possible to account fully for the clinical features of CP on the basis of a vasculitis and a biologically inferior bone This vasculopathy which is a constant feature in all the cases examined may cause one of infarction necrosis In addition a well documented arterial communication between the upper and lower cervical circulation in the female can be the explanation of the differences of incidence of CP in the two sexes

To summarize all the above data viz clinical histological and particularly immunological aspects indicate the need for a discussion of a probable etiologic correlation between prenatal rubella and CP Despite absence of lesions classically associated with rubella syndrome this osseous disorder may represent a forme fruste of that disease It is very likely that CP is not a localized disorder nor a distinct entity but the late osseous residua or stigma of very mild prenatal viral infection with a sub clinical course in the mother If that is true a progressive disappearance of CP is possible in the future


## SUMMARY

The present study seriously raises the question as to whether coxa plana is etiologically connected to the rubella virus Some findings suggests a probable causal correlation between prenatal rubella and coxa plana A regional vasculitis in association with biologically inferior bone probably constitutes the fundamental pathogenetic mechanism of this condition However this matter is still awaiting elucidation

*were not obtained Only three* controls had positive sera but the geometric mean titers of these were much lower than those of the test mothers

2 Neutralizing antibodies particularly IgG (7S) persist in all the test children and the same antibodies persist to detectable levels in all the test mothers This pattern was in marked contrast to the pattern of both control groups Actively acquired IgG appears to be the dominant rubella antibody in all affected children Among the controls higher levels of antibody were found in only two Half of the *control mothers were negative whereas the other half showed minimal levels of IgG*

In conclusion, the pattern of antibody response of the patients and their mothers differs significantly *from the pattern of the controls The main difference* lies in the higher levels of antibodies in all the affected children and in all their mothers

## *Part III Histologic study*

Vascular lesions were studied in five children with CP in connection with surgical intervention The vulnerable vascular channels are the cervical branches arising from the cervical circle and which traverse the joint cavity to reach the capital femoral epiphysis Several such cervical branches have been examined The severity of involvement varied No significant lesions were found in *arterioles or* veins Diffuse proliferation of the arterial intima was the most characteristic lesion in all these cases At some sites the intima was more than twice as thick as the remaining arterial wall The internal elastic lamella and media were almost always unchanged, even in the presence of a greatly thickened intima (Figure 1) Conclusion The characteristic finding was intimal fibromuscular proliferation

## DISCUSSION

The surprising findings of the present study provide some support for the suggestion that CP probably reflects the effect of rubella virus during the prenatal period It is well known that the multiplicity of defects is the striking feature of congenital rubella in children

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Acta orthop scand 46, 963–967, 1975

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# PEROPERATIVE EFFECT OF FENESTRATION UPON INTRAOSSEOUS PRESSURE IN PATIENTS WITH OSTEOARTHRITIS OF THE HIP

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Accepted 24 i 75

The favourable effect of osteotomy upon pain at rest* in patients with osteoarthritis of the hip was thought by McMurray (1935) to be the result of alterations in mechanical factors while Nissen (1963) thought it to be due to a reduction of arterial hyperaemia. Venable & Stuck (1946) as well as Palazzi (1957 58) observed immediate relief of pain on resecting a fragment of cortical bone from the femoral neck. This relief of pain was explained as being the result of "decompression of bone

Phillips (1966) demonstrated a delay in venous blood drainage with subsequent intraosseous blood congestion in coxarthrosis. Arnoldi et al (1971) recorded an increased intraosseous pressure in the proximal femur in patients with coxarthrosis who experienced pain. An immediate decrease of intraosseous pressure was noted both during intertrochanteric osteotomy as well as during fenestration of the femoral head. Further "normalization" of the venous blood drainage was demonstrated after osteotomy by Phillips et al (1967)

These findings point towards a connection between pain, elevation of intraosseous pressure and impaired drainage conditions. Further, they suggest that the immediate relief from pain after osteotomy and fenestration may be due to a lowering of intraosseous pressure

The aim of the present study was to investigate the peroperative effect upon intraosseous pressure in the femoral head and neck brought about by a fenestration procedure in the trochanter major in patients with osteoarthritis and pain

* In the following the term pain means pain at rest

## ACKNOWLEDGEMENTS

We would like to thank Associate Professor Euthymios Stoforos Director of the Immunological Research Unit of Athens We are indebted to Dr Ira Tsimaras for the careful examination of our vascular specimens

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*Key words* coxa plana prenatal rubella

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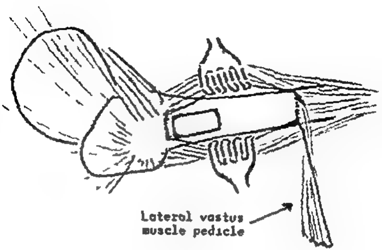


*Figure 1 Lateral aspect of the femur with the middle part of the lateral vastus muscle detached from the greater trochanter. Fenestration of cortical bone performed distal to the greater trochanter*

## RESULTS

The individual intraosseous pressures before and after fenestration are shown in Table 1. It can be seen that in the femoral neck lower pressures were found after the fenestration procedure in all patients. In the femoral head the pressure was found to be lower in eight out of nine cases. In the ninth case the pressure remained unchanged after the fenestration procedure. The reduction of intraosseous pressure was more pronounced in the femoral neck than in the head.

## DISCUSSION

The patients in the present study represent different degrees of osteoarthritis but they had pain as a common symptom. Three patients had a clinical and radiographic picture not severe enough to justify major surgery. Six patients had severe osteoarthritis. The mean pressures in the femoral neck and head were found to be high compared to the pressure values found in radiographically normal hips by Arnoldi et al (1972). These "normal values" were derived from the contralateral hip from patients undergoing operation for severe osteoarthritis in one

## MATERIAL

The material included nine patients, seven women and two men, with degenerative *osteoarthritis of the hip joint* Average age at the time of operation was 56 years (range 21–67 years) All patients suffered from pain

Pain was defined as a dull ache, in the area of the affected joint, which frequently radiated along the inside of the thigh down to the knee Its presence was independent of body posture and could not be relieved either by reduction of strain upon the affected joint or by a specific resting position of the limb Pain was often aggravated by foregoing strain, but such aggravation frequently reached its maximum several hours after the triggering strain had ceased

In all patients pain was a dominating symptom even though different degrees of osteoarthritis were represented in the material None of the patients showed any signs of cardiac failure or arterial hypertension

## GENERAL PROCEDURES

Each patient was informed about the aim of the operation and was also aware of the fact that this operation could not be guaranteed to produce long term pain relief

### *Surgical technique*

The operation was performed under extradural anaesthesia A lateral incision was made, exposing the greater trochanter and the proximal insertion of the lateral vastus muscle The middle part of this muscle was detached and a pedicle of about 10 *cm length was dissected free The lateral aspect of the femur* just distal to the greater trochanter was thus exposed and a 1×2 cm sized fragment of cortical bone was removed by means of a saw (Figure 1) The underlying cancellous bone was kept intact The tip of the muscle pedicle was secured to the frames of the cortical window by four osteosutures This fixation of the muscle pedicle was carried out in an *attempt to prevent future healing of the window* The resection lines of the lateral vastus muscle were sutured lateral to the pedicle Fascia lata and skin were sutured after placing a suction drain in the operation area

### *Intraosseous pressure recordings*

*Pressure registration was performed by means of the same* technique and with the same equipment as described by Arnoldi et al (1971) After preparation of the above mentioned muscle pedicle two metal needles were inserted under two plane X ray supervision One needle was placed with its tip as close to the centre *of* the femoral head as possible and the other needle with its *tip in the centre* of the *femoral neck* in line with the intertrochanteric crista The needles were located in such a way that they would not interfere with the following fenestration procedure Pressures in the femoral neck and head were recorded immediately before and immediately after removal of the window of cortical *bone Pressure* readings were related to the level of the mid axillary line which was assumed to represent the level of the heart with the patient in supine horizontal position Venous pressures were not recorded since they were considered to be of minor interest in the context of this study

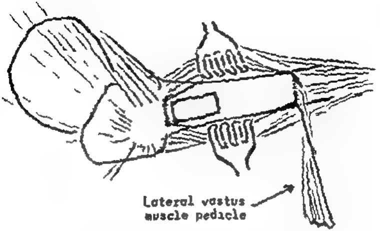


*Figure 1 Lateral aspect of the femur with the middle part of the lateral vastus muscle detached from the greater trochanter Fenestration of cortical bone performed distal to the greater trochanter*

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## DISCUSSION

The patients in the present study represent different degrees of osteoarthritis but they had pain as a common symptom Three pat-

... found to be high compared to the pressure values found in radiographically normal hips by Arnoldi et al (1972) These "normal values" were derived from the contralateral hip from patients undergoing operation for severe osteoarthritis in one

*Table 1. Intraosseous pressures in relation to heart level recorded before and after fenestration in nine patients suffering from osteoarthritis of the hip with pain at rest as a dominating symptom*

| Patient | | Intraosseous pressure before fenestration | | Change (in mmHg) of intraosseous pressure after fenestration | |
|---|---|---|---|---|---|
| Sex | Age | P = caput | P = collum | Caput | Collum |
| F | 49 | 37 4 | 34 4 | — 2 9 | — 6 2 |
| M | 66 | 26 7 | 24 0 | — 3 0 | — 2 7 |
| F | 66 | 55 6 | 42 5 | — 4 2 | —15 7 |
| F | 63 | 48 7 | 20 6 | —14 2 | — 4 3 |
| F | 21 | 30 0 | 26 6 | — 9 9 | — 8 5 |
| F | 56 | 99 7 | 96 4 | — 8 2 | —24 7 |
| F | 67 | 45 0 | 36 2 | ± 0 0 | — 9 6 |
| M | 53 | 41 5 | 27 9 | — 1 3 | —12 6 |
| F | 64 | 52 1 | 34 9 | — 9 0 | —12 7 |
| $\bar{m}$ | | 48 5 | 38 2 | — 5 9* | —10 8* |

P = intraosseous pressure in mmHg
$\bar{m}$ = mean pressure, mean reduction
F = female
M = male
* = reduction significant at the 1 per cent level of probability according to sign test

hip In this study pain was only observed in patients with intraosseous pressure in the femoral neck of above 40 mmHg In the present study pressure values above 40 mmHg in the femoral head were present in six out of nine patients preoperatively

The fenestration operation is a minor surgical procedure which gives an immediate reduction of intraosseous pressure in the femoral head and neck in the majority of treated patients This simple operation may be justified if the follow-up study now being carried out shows a reduction of pain over a reasonable period of time

## SUMMARY

In nine patients with osteoarthritis of the hip who suffered from pain at rest, intraosseous pressure was measured in both the femoral head and neck before and immediately after fenestration in the lateral aspect of the greater trochanter A small but significant drop in intraosseous pressure in both the femoral neck and head was registered as a result of the fenestration procedure

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*Key words:* coxarthrosis, fenestration, interosseous pressure, peroperative effect upon

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Acta orthop scand 46 968–978, 1975

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# INFECTION FOLLOWING TOTAL HIP REPLACEMENT IN A GENERAL HOSPITAL WITHOUT SPECIAL ORTHOPAEDIC FACILITIES

M K D BENSON & S P F HUGHES

Accepted 28 iv 75

Total prosthetic replacement of the hip has become a standard orthopaedic procedure A serious complication is for infection to occur as it results not only in pain in the hip, but it may lead to further disability and eventual removal of the whole prosthesis

Charnley & Eftekhar (1969) investigated this problem and showed that the incidence of infection could be reduced by using a specially designed operating theatre incorporating a system of nearly sterile air with laminar flow However, not all hospitals have these facilities and we have reviewed the incidence of infection among patients who have had a total hip replacement undertaken in a general hospital without special orthopaedic theatres

## METHOD

All total hip replacements performed at The Middlesex Hospital from 1968 to 1972 inclusive have been reviewed There were 274 patients who had 321 arthroplasties 202 women and 72 men The mean age was 63 years (Figure 1) and the average follow up period was 2 years (Figure 2)

*The operations were performed in general theatres* which were built in 1936 two further theatres were added in 1968 The plan of the operating suite is shown in Figure 3 The theatres are situated on the top floor of the six storey hospital The clean zone includes the changing and recovery rooms dirty material is dispersed through a clean corridor to a sluice and holding area The scrub room is incorporated in the operating theatre but the sterilising and anaesthetic rooms are separate The ventilation system is designed to give a minimum of 15 air changes each hour in the theatre Air enters from outside through high level wall ducts and is extracted through low level vents With this system the air flow is turbulent rather than laminar Air filters remove particulate matter greater than 5 $\mu m$ in diameter This is an effective barrier to dust particles but not to isolated bacteria

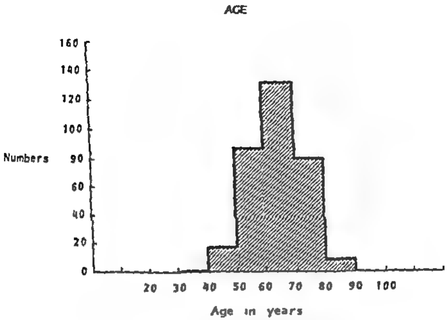


*Figure 1*

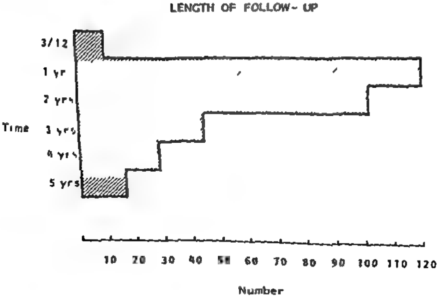


*Figure 2*

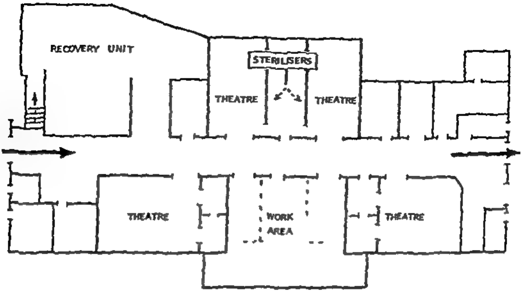


*Figure 3*

However, bacteria are rarely completely unattached to particulate matter and particles which carry pathogenic bacteria have a medium diameter of 12 μm (Noble et al 1963) In practice, therefore, a 5 μm filter is highly efficient (Blowers & Crew 1960)

No theatre is reserved entirely for orthopaedic use, general surgeons, urologists gynaecologists, cardiothoracic and neurosurgeons all operate in these theatres No theatre is used for 2 hours after an operation on a patient who is potentially or actually infected In addition to the normal attendants at a major operation, there are always some medical and nursing students in the theatre itself The spectators are encouraged to remain as still as possible, as activity has been shown to increase the content of bacteria in the air (Bruckner & Jessen 1963)

Patients are admitted to the orthopaedic ward 24 to 48 hours before operation In the theatre, the skin is cleaned with 0 5 per cent chlorhexidene in 70 per cent alcohol No patient received prophylactic antibiotics, but one third had chloramphenicol powder inserted into the wound at the end of the operation A closed system of drainage was used in all patients and the types of replacement included McKee-Farrar, Charnley and Stanmore, one patient had a Howse prosthesis

As infection following hip replacement can become apparent at any stage after the operation, we arbitrarily divided infections into those occurring early, within 3 months of the operation and those occurring late more than three months after the operation The diagnosis of early infection rarely presents a problem the patient has continuous severe pain is obviously unwell usually has a fever and frequently has a discharge from his wound The white cell count is elevated and pathogenic organisms can almost always be cultured By contrast late infections may prove difficult to distinguish from mechanical disorders, or from immune reactions based on metal sensitivity The patient has pain but is generally well frequently afebrile and often has a normal white cell count We considered late infection to be present when two or more of the following criteria were present

a) pain in the hip at rest and on movement
b) a persistent sinus in communication with the hip joint
c) pathogenic organisms isolated from the hip joint either by discharge, aspiration or at operation
d) an ESR that is 30 mm/hour above the pre-operative level, in the absence of other causes for the elevation
e) radiological evidence of infection, that is, periosteal reaction, bone resorption and progressive erosion of the calcar femorale

## RESULTS

Of the 321 hip arthroplasties performed, 17 became infected, an incidence of 5 3 per cent Nine of these infections were early (2 8 per cent) and eight were late (2 5 per cent) Six of the 103 patients who had chloramphenicol powder inserted into the wound at the end of the operation developed an infection, compared with 11 out of 218 who did not There was, therefore, no statistically significant difference in the infection rates of those patients with local antibiotic powder applied to the wound and those without

The organism isolated from the infected hips showed a wide variety (Table 1) There was no obvious difference in the type of organism cultured from the early infections and that cultured from the late infections It was notable that several of the organisms cultured were of the supposedly less virulent type, and are usually regarded as skin commensals only Whether *staphylococcus albus* may be considered pathogenic and be responsible for deep infections in the abnormal environment created by a hip arthroplasty remains uncertain

In all 17 infections, the patient complained of severe pain in the hip although not abolished by rest, the pain was aggravated by movement None of the patients with late infection showed signs of

*Table 1 Organisms isolated*

| Organism | Early | Late |
|---|---|---|
| *Staphylococcus aureus* | 2 | 1 |
| *Escherichia coli* | 3 | 1 |
| Proteus species | 1 | 1 |
| *Pseudomonas aeruginosa* | 2 | — |
| *Streptococcus faecalis* | 2 | 1 |
| *Staphylococcus albus* | 2 | 2 |
| Micrococci or diphtheroids | 1 | 2 |

*Table 2. X-ray changes in 17 patients.*

| Change | Minimal | Marked |
|---|---|---|
| Periosteal reaction | 4 | 7 |
| Resorption of the calcar femorale | [illegible] | [illegible] |
| Bone destruction | 4 | 3 |

systemic upset, and none complained of general ill health or of fever. The patients who developed what was regarded as late infection were initially pain-free following their arthroplasty. Similarly, the white cell count was not raised. The E.S.R., however, was elevated, ranging from 44 to 120 mm/hour (mean 65 mm/hour). The E.S.R. varies with surgery and usually increases by about 30 mm/hour, returning to its original level at [illegible] weeks (Hughes 1966).

Radiographic evidence of infection about the prosthesis is shown in Table 2. The most constant findings were periosteal reaction around the shaft of the femur and resorption of the calcar. Periosteal reaction about the acetabulum was not seen even in the presence of gross acetabular loosening and migration resulting from infection. Charnley (1967) believes that resorption of the calcar is a physiological effect and that

*Figure 4.*

*Figure 5*

the resorption confirms the efficacy of weight transmission by cement low down in the medullary cavity In this physiological resorption, however, there is a smooth loss of the full thickness of the calcar, while in the infective process, the calcar is irregularly eroded Bone resorption was also seen in the greater trochanter but infrequently in the femoral shaft (Figures 4 and 5)

In 10 of the 17 patients with infection, sinograms were performed and these confirmed a direct communication with one or both of the components of the hip prosthesis Bone scans, using ethylhydroxydiphosphonate, were performed on three patients, and each demonstrated increased isotope uptake about the infected prosthesis (Figure 6)

The incidence of infection was no different, whether Consultants or Senior Registrars performed the operation Out of 321 hip replacements, there were 118 McKee-Farrar, 161 Charnley, 41 Stanmore and one Howse The rate of infection was 7 6 *per cent*, 4 8 per cent and 0 per cent, the single Howse replacement became infected The length of follow-up for the McKee-Farrar, Charnley and Stanmore was 5, 4 and 2 years respectively, and for this reason the relative rates of infection are not statistically significant

Of the eight patients with late infection, three gave a clear history of a recent intercurrent infection One patient had a dental abscess and

*Figure 6*

one an infected ulcer, however, both these were treated before their hip infection developed and there is unfortunately no record of the pathogenic organism The third patient had had a urinary tract infection caused by a coliform organism of exactly similar sensitivity as that subsequently isolated from the infected hip prosthesis Three other patients had episodes of trauma to their hip prior to the onset of infection In each case, the initial pain of their fall was completely relieved before the persistent deep pain of infection developed No patient who had bilateral arthroplasties developed infection in both hips

Eleven of the 17 patients with infection have had Girdlestone arthroplasties Of the remaining six, one has died and five are either unwilling or not sufficiently incapacitated for the prosthesis to be removed

## DISCUSSION

We have found that the incidence of infection following total hip replacement in this retrospective series compares favourably with that reported by others (Table 3) Most authors (Patterson & Selby Brown 1972, Charnley 1972, Harris et al 1972 Todd et al 1972, Sillar & Connor 1971, Ericson et al 1973 and Arnett 1973) agree that infection

*Table 3 Comparative rates of infection*

| e | Year | Number | Early % | Late % | Total % | Type of theatre prosthesis and prophylaxis |
|---|---|---|---|---|---|---|
| rnley | 1965 | 582 | 1 6 | 2 2 | 3 8 | Special orthopaedic theatre 130 air changes/hour Charnley No prophylaxis |
| rnley | 1969 | 708 | 1 0 | 0.3 | 1.3 | Special orthopaedic theatre 300 air changes/hour "Laminar flow" Charnley No prophylax s |
| es | 1971 | 471 | | - | 5 9 | General theatre Knees and hips replaced Mixed prophylactic antibiotics |
| ar | 1971 | 60 | 1 6 | 1 6 | 3.2 | Orthopaedic theatre Charnley Gentamycin Cloxacillin and Ampicillin |
| rris | 1972 | 73 | 7 0 | 3 8 | 10 8 | General theatre Charnley Rheumatoid arthritis Ampicillin and Cloxacillin |
| dd | 1972 | 320 | 2 5 | 2 8 | 5 3 | General theatre Charnley Amp cillin and Cloxacillin |
| terson | 1972 | 368 | 2 99 | 5 16 | 8 15 | Orthopaedic theatre McKee No prophylaxis |
| rtson | 1973 | [illegible] 60 | 0 | 0 | 0 0 | Orthopaedic theatre Charnley Probenecid and Cloxacillin |
| o entry | 1974 | 2 012 | | | 0 6 | Orthopaed c theatre Charnley Methicill n |
| he M ddlesex | 1974 | 321 | 2.8 | 2 5 | 5 3 | General theatre McKee Charnley Stanmore and Howse No prophylaxis |

following prosthetic replacement may occur either early or late There is disagreement however as to why late infections occur Late in fections may arise because bacteria introduced at the time of the opera tion become activated or because the prosthesis may be the site for bacteria to settle during a bacteraemia A significant bacteraemia may be produced by trauma burns or intercurrent infections (Lerner &

Weinstein 1966 a) and the possible effects of a bacteraemia on patients who have damaged heart valves are well established Patients with abnormal heart valves are advised to avoid these procedures, including dental or urological manipulations, which might provoke bacteraemia, unless they are adequately protected by prophylactic antibiotics (Lerner & Weinstein 1966 b) It may be that patients with hip prostheses should be similarly protected

Certainly, intercurrent infections, no matter how trivial, should be treated with the appropriate antibiotics for a period sufficient to cover any bacteraemia which may arise Similarly, all injuries to the hip joint should be taken seriously and the patient given a prophylactic antibiotic, as a local haematoma formation following such an accident may act as a suitable culture medium for bacteria to grow and for infection to take place

In order to reduce the per-operative rate of infection, Charnley (1968) has paid particular attention to the air in the theatre He operates in an isolated chamber in which the air is filtered to 1 μm and delivered at 4,500 cf/min A system of aluminium diffusion vanes attempts to distribute the air flow in a linear fashion Air enters through the ceiling and is dispersed at ground level, it is changed 300 times per hour The air inside the operating enclosure is, therefore, of high sterility and the ventilation approximates as closely as possible to the ideal of laminar flow To prevent bacterial contamination by the surgeon and his assistants, each wears a totally investing helmet and gown with individual exhaust systems to remove convection currents, skin scales and exhaled breath

In a busy general theatre such as that of The Middlesex, used by a variety of surgical specialities, such a system would be difficult to emulate Therefore, in addition to standard precautions against infection, the use of prophylactic antibiotics may be considered Scales et al (1972) reviewed 1,623 patients who had metal implanted during various orthopaedic operations and found that the incidence of wound infection could be reduced from 8 8 per cent to 5 3 per cent by introducing antibiotics into the wound during the operation In our patients, however, the use of chloramphenicol powder made no difference to the infection rate, early or late Coventry et al (1974) reported a 0 6 per cent infection rate, following total hip replacement They gave Methicillin systemically as a prophylactic and operated in theatres reserved entirely for orthopaedic use Ericson et al (1973) showed that prophylactic Cloxacillin can reduce the infection rate from

13 per cent to 0 per cent in early infection and from 14 per cent to 0 per cent in late infections However, the total follow up was only 2½ years their series included fractured necks of femurs and the operations were performed entirely in orthopaedic theatres Because of the wide variety of organisms cultured from infected hip prostheses, we believe that a single anti staphylococcal antibiotic may not be adequate protection and that a broader spectrum antibiotic given systemically at the time of the operation may be more effective

## SUMMARY

Infection following total hip replacement is a serious complication for it is frequently impossible to resolve without removal of the prosthesis

We have reviewed 321 total hip replacements undertaken in a general hospital without special orthopaedic theatres There were 17 deep infections, nine early and eight late Although the diagnosis of early infection is usually not difficult, the differentiation between late infections mechanical failure and metal sensitivity may be a problem This paper discusses the use of ESR, radiographs, isolation of pathogenic organisms and bone scanning in reaching the diagnosis of infection of the hip

There is possibly a parallel between prosthetic infection and subacute bacterial endocarditis Therefore all intercurrent infections and episodes of trauma should be given an adequate course of a broad spectrum antibiotic Sterile air and laminar flow systems are discussed and compared with prophylactic antibiotics, both systemic and local, in attempting to reduce the overall rate of infection following total replacement of the hip

## ACKNOWLEDGEMENTS

We should like to express our thanks to Mr P H Newman and Mr D R Sweetman for allowing us to study their patients and to Mr Sweetman and Dr R E M Thompson for their help and advice in preparing this paper

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Acta orthop scand 46 979 986, 1975

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# CHONDROCYTE MITOSIS IN THE ARTICULAR CARTILAGE OF FEMORAL HEADS WITH VARIOUS DISEASES

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Accepted 24 iv 75

It is well known that no chondrocytes have mitotic activity in the normal articular cartilage of adult human beings and animals (Mankin 1962 a, b) However, Trias (1961) and Crelin & Southwick (1960, 1964) observed mitotic figures of chondrocytes in the knee joints of adult rabbits under compression DePalma et al (1966) demonstrated autoradiographic evidence of thymidine-³H uptake in reparative tissue filled full thickness defects surgically created Furthermore, labelled chondrocytes with tritiated thymidine were recognized not merely in autologous diced costal cartilage implanted intramuscularly and intraarticularly (Lemperg 1967) but also in the costal cartilage transplanted to the joint cartilage defects (Hjerquist & Lemperg 1969)

Recently, Swedish and British investigators (Hulth et al 1972, Telhag 1972, 1973, Rothwell & Bentley 1973) have emphasized that the thymidine-³H uptake can be demonstrated in articular chondrocytes both in experimental animals and in human hips with osteoarthritis

Although it is acceptable that the degeneration of cartilage may provoke reparative responses including mitosis of chondrocytes, anatomical and metabolic changes in the cartilage matrix in which dividing chondrocytes are embedded are not clearly demonstrated

The present study is undertaken to answer the question whether or not the mitotic figures of chondrocytes can be found in secondary osteoarthritis and other pathologic conditions of the hip joint and also to reveal the pathologic characteristics of the cartilage matrix showing mitotic figures of chondrocytes

## MATERIALS AND METHODS

Femoral heads were obtained at the time of operation from [illegible] patients with various abnormalities of the hip (Table 1) Small blocks of articular cartilage with

underlying bone were taken from the zenithal area and the medial margin of the joint cartilage under sterile conditions The specimens were immediately immersed at 36 5° C in Eagle MEM medium* containing 10 microcuries of thymidine-³H (specific activity 5 0 Ci/mM, the Radiochemical Centre, Amersham England) per milliliter After 4–24 hours incubation, specimens were rinsed with physiologic saline solution and fixed in 10 per cent buffered formalin After decalcification with 10 per cent EDTA solution, dehydration and embedding in paraffin sections were cut at 6 microns

*Table 1 Number of femoral heads investigated*

| Abnormalities | | No of cases |
|---|---|---|
| *Secondary osteoarthritis* | | 21 |
| Due to congenital dislocation of the hip | 20 | |
| Due to spondyloepiphyseal dysplasia | 1 | |
| Aseptic necrosis of the femoral head | | 8 |
| Idiopathic | 7 | |
| *Posttraumatic* | 1 | |
| Ununited intracapsular fracture of the femoral neck* | | 24 |
| Traumatic | 20 | |
| $^{60}$Co irradiated | 4 | |
| Total | | [illegible] |

* Femoral heads were obtained from 3 days to 4 years and 4 months after fracture

Autoradiography was processed by the dipping method Preparations were exposed in a dark, dry room at 4° C for 4 weeks After developing and fixation sections were stained with hematoxylin eosin, Other sections were stained with either hematoxylin eosin for cellular details or safranin O fast green iron hematoxylin for acid glycosaminoglycans (Rosenberg 1971) Since an uncontrolled loss of glycosaminoglycans from the articular cartilage occurs after incubation (Ozerkis & Zarins 1971, Larson & Lemperg 1974), intensity of safranin O stain in the specimens was carefully judged by comparing it with that in specimens which were taken from the adjacent area and processed without incubation

Histopathological changes were assessed using the numerical scales of the histological and histochemical grading system described by Mankin et al (1971)

## RESULTS

Chondrocytes labelled with thymidine-³H (Figures 1 & 2) were found in five specimens from the 21 cases with secondary osteoarthritis of the hip, in four from the eight with aseptic necrosis of the femoral

* Eagle MEM medium used is Minimum Essential Medium Eagle with Earle s Balanced Solution

*Figure 1* Mitotic chondrocytes in clusters Arrows indicate the labelled cells (Articular cartilage from a case with secondary osteoarthritis of the hip × 40

head but in none of the 27 with ununited fracture of the femoral neck Of all nine specimens containing labelled cells, six were found in the specimens taken from the zenithal area of the head and three from the marginal portion of the cartilage, the incidence being almost the same

One to four labelled chondrocytes were observed in each specimen Thymidine-³H was incorporated by either one or two cells within a cluster (Figure 1) or an isolated chondrocyte (Figure 2), the former being more frequently observed Chondrocytes in the transitional zone of the cartilage exclusively showed a predilection for labelling

In the cartilage in which mitosis was recognized, safranin-O staining was reduced in the interterritorial matrix with evidence of a positive reaction surrounding chondrocyte lacunae (Figure 3) As shown in Figure 4 histological and histochemical grades of these cartilage specimens ranged from six to ten on their numerical scale Scores of each criterion are presented in Table 2

*Figure 2 Isolated chondrocyte labelled with tritiated thymidine (Articular cartilage from a case with idiopathic necrosis of the hip × 163*

*Table 2 Distribution of scores in nine specimens with mitotic activity*

| | Case No | Histological and histochemical grade I Structure | II Cell | III Safranin O staining | IV Tidemark integrity | Total |
|---|---|---|---|---|---|---|
| Osteoarthritis | | | | | | |
| Zenith | 1 | 3 | 2 | 1 | 1 | 7 |
| | 2 | 3 | 2 | 3 | 1 | 9 |
| | 3 | 4 | 3 | 1 | 1 | 9 |
| | 4 | 3 | 3 | 3 | 1 | 10 |
| Margin | 5 | 2 | 2 | 3 | 1 | 8 |
| Aseptic necrosis | | | | | | |
| Zenith | 6 | 3 | 2 | 1 | [illegible] | [illegible] |
| | 7 | 2 | 2 | 2 | 1 | 7 |
| Margin | 7 | 2 | 2 | 2 | 1 | 7 |
| | 8 | 2 | 2 | [illegible] | 1 | 7 |

Figure 3 Histology in the area adjacent to Figure 1 Safranin O fast green stain × 33

## DISCUSSION

The results obtained clearly demonstrated that labelled chondrocytes can be seen in the articular cartilage of both secondary osteoarthritis and aseptic necrosis of the femoral head It is reasonable to assume that articular chondrocytes in degenerative joint disease restore the mitotic activity and that a hypercellularity and a cluster formation may have resulted from mitotic cell division, as previously stated by Hulth et al (1972) and Telhag (1972, 1973)

Articular cartilage containing mitotic chondrocytes shows a remarkable degradation of the interterritorial matrix glycosaminoglycans as judged by reduced safranin O stain The depletion of matrix glycosaminoglycans may offer a predisposing basis for switching on the DNA synthesis activity of chondrocytes in the mature articular cartilage The fact that glycosaminoglycans of the matrix are initially degraded in the superficial part of the cartilage supports the finding that the

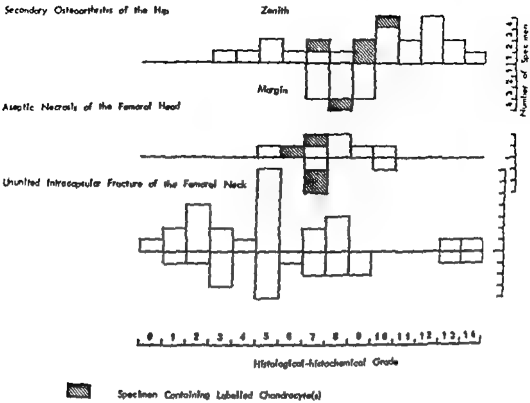


*Figure 4 Incidence of mitotic chondrocytes in various diseases of the hip*

labelled chondrocytes are situated in the transitional zone of the cartilage

The evidence that chondrocytes in the femoral heads of ununited neck fracture show no mitosis leads to a speculation, suggested by previous experiments, that a biomechanical factor seems to play an essential role in provoking mitotic activity of chondrocytes (Trias 1961, Crelin & Southwick 1960, 1964)

The articular cartilage from the heads with aseptic necrosis showed the radioactive thymidine uptake in chondrocytes In these specimens, subchondral bone was totally dead, the evidence being confirmed by data from another of our investigations using the NADH dehydrogenase reaction (Brucke et al 1967) The result lends additional support to the concept that the adult articular cartilage is nourished solely by the synovial fluid and is not dependent on the viability of subchondral bone Hodge & McKibbin 1969, Honner & Thompson 1971)

In the present study, histological and histochemical changes are studied to elucidate the anatomical basis responsible for mitosis of chondrocytes Labelled cells are exclusively found in the degenerated

cartilage which ranged from six to ten on the numerical scale of the histological and histochemical grading system The results are coincident with that of biochemical studies reported by Mankin et al (1971) According to them, the thymidine incorporation by degenerated cartilage increased until it reached a score of about ten A decreased incorporation is observed with increasing scores over that grade It is possible to state that the reparative process by multiplying chondrocytes by means of mitosis also has "the point of irreversibility" proposed by Mankin (1971) Over that point, complete degradation of the matrix may ensue, finally resulting in chondrocyte death

## SUMMARY

Autoradiographic studies using thymidine ³H reveal the mitosis of chondrocytes in degenerated joints, i e joints having secondary osteoarthritis or aseptic necrosis of the femoral head The findings obtained provide additional support for the recent investigations regarding chondrocyte mitosis in primary osteoarthritic cartilage Histologic and histochemical examinations suggest that a loss of glycosaminoglycans in the matrix is evidence for conversion of chondrocyte activity to mitosis which occurs however within the limit of "the point of irreversibility" analogous to the observations from the biochemical point of view Biomechanical and nutritional factors are also discussed in relation to the results obtained from cartilages of the femoral heads in cases of femoral neck fracture and aseptic necrosis of the femoral head

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*Key words* cartilage articular femur head necrosis fractures mitosis osteoarthritis

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Acta orthop scand 46, 987–995, 1975

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# ACUTE SLIPPED CAPITAL FEMORAL EPIPHYSIS

## *Treatment in 8 Cases*

H Overgaard Nielsen

Accepted 27 v 75

The literature on slow gradual slipping of the upper femoral epiphysis is comprehensive Oram (1952), Salenius & Kivilaakso (1968), Sorensen (1968), and others In the case of acute (traumatic) slipped capital femoral epiphysis, however, reports presenting both the treatment applied and the results achieved are scanty The treatment of this acute condition is also uncertain, often resulting in a defective hip (Ratliff 1968)

The present communication is intended as a contribution to the discussion on results obtained by various methods of treatment, compared to the results achieved by the treatment as laid down by Watson Jones (1946)

### MATERIAL AND METHOD

A total of 75 patients with slipped capital epiphysis have undergone treatment in the Orthopaedic Department of Holstebro Central Hospital during the period 1958 1972 Of this total eight all boys were acute cases according to the definition of Fahey & O'Brien (1965) The average age was 13 years (10 to 15 years) Five were of the obese type six had some discomfort for periods of from 3 weeks to 6 months in the hip which subsequently received treatment The trauma was moderate in all patients but following the trauma none of the patients was able to bear any weight on the leg on account of pain and in all cases shortening of the leg was demonstrated as well as external rotation Admission to the department took place from 1 to 5 days after the trauma all patients being admitted originally as acute cases to the local hospital The degree of slipping varied from $\frac{1}{4}$ to $\frac{1}{2}$ of the width of the neck of the femur

Immediately after admission wire traction was applied through the tubercle of the tibia with an average load of 6 5 kg (from 2 to 10 kg) Satisfactory reduction was obtained in an average of 12 days (6 to 23 days) and the position was immobilized by internal fixation with Kirschner wires, three of which were left in place for subsequent removal at the earliest on closure of the epiphysis Post

*Table 1 Physical examination and roentgenological findings on follow up examination of eight patients treated for acute slipped capital femoral epiphysis by forceful traction followed by drilling through with Kirschner wire*

| No | Period of observation | Physical examination | Roentgenological findings |
|---|---|---|---|
| 1 | 12 years | Normal conditions | Slight deformation of the head and neck of femur |
| 2 | 3 years | 1 cm shortening otherwise normal | Slight deformation of neck head normal |
| 3 | 11 years | Normal conditions | Normal conditions |
| 4 | 6 years | 1 cm shortening loss of inward rotation | Slight deformation of the head and neck of femur |
| 5 | [illegible] years | 1 5 cm shortening, otherwise normal | Slight deformation of the head and neck of femur |
| 6 | 11 years | Severely limited motion | Pronounced degenerative arthritis |
| 7 | 2 years | Normal conditions | Normal conditions |
| 8 | 3 years | Normal conditions | Normal conditions |

operatively, traction was maintained by skin traction on the lower limb from 5 to 44 days with a load of from 1 to 5 kg The patients were then ambulatory with the help of a Thomas splint until the closure of the epiphyseal line The time elapsing from the start of treatment until a roentgenogram showed closure of the epiphysis varied between 4 and 6 months

## RESULTS

The subsequent course has been free from complications, and in particular none of those who have received treatment have shown any signs of development of necrosis of the epiphysis

The patients were followed up from 2 to 12 years after treatment (Table 1) None of them reported any discomfort from the treated hip A physical examination showed normal motion of the hip in six patients, inward rotation was lost in two patients, and in one of these there was in addition limitation of flexion and outward rotation In three patients there was shortening of from 1 to 1 5 cm Roentgenograms showed normal conditions in three patients (Figure 1 a–c) In four patients the picture on the affected side, compared to the

*Figure 1a Roentgenological examination of both hip joints of a 15 year old boy (No 3) 1 day after minor trauma to the right hip showing pronounced slipping on the right side*

*Figure 1b Same patient 23 days later after traction and fixation with Kirschner wires*

healthy side was one of slight to moderate deformity of the femoral neck in the form of shortening together with flattening of the head (Figure 2 a–c) One patient had obvious signs of degenerative arthritis, with narrowing joint space, sclerosis and exostosis (Figure 3 a–c) On follow up examination, two of the patients had slight lateral instability

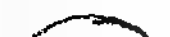

*Figure 1 c. Same patient 11 years later, showing normal conditions*

in the extended knee. This must be ascribed to the forceful traction during the treatment. The looseness did not give rise to any complaints. Two patients who were of the obese type at the time of treatment had developed normal body build by the time of follow-up, whereas three patients were still severely obese.

It might be mentioned that 7 months after treatment on the one side, patient no. 8 developed acute slipped capital femoral epiphysis on the

*Figure 2 a. Roentgenological examination of both hip joints of a 12 year old boy (No. 1), a few hours after a minor trauma to the left hip showing pronounced slipping on that side*

*Figure 2 b Same patient 6 days later, after traction and fixation with Kirschner wires*

*Figure 2 c Same patient 12 years later Flattening of the head of femur and shortening of the neck so that the trochanter major almost reaches the same level as the head*

other side The treatment of this hip has not been included in the present investigation, as the period of observation was less than 2 years but in this case also no necrosis of the head of the femur was found to have developed 12 months after the start of treatment

*Figure 3 a. Roentgenological examination of the left hip joint of a 14 year old boy (No 6) a few hours after a minor trauma to the left hip showing pronounced slipping*

*Figure 3 b Same patient 15 days later after traction and fixation with Kirschner wires*

*Figure 3 c Same patient 11 years later, with pronounced degenerative arthritis on the left side compared with the right hip*

## DISCUSSION

Traumatic epiphyseolysis of the proximal end of the femur is far more uncommon than slow, gradual slipping in the literature it is reported as amounting to 5 25 per cent of all cases In acute slipping, there is the possibility of achieving an anatomically correct reduction, as reparatory changes which hinder this have not yet occurred Reduction must be regarded as being of great significance in avoiding subsequent development of degenerative arthritis The reduction may be by manipulation under general anaesthesia (Barash et al 1971, Casey et al 1972, Fahey & O Brien 1965) but it is not unusual for the treatment to be accompanied by serious complications in the form of necrosis of the epiphysis Casey et al (1972) have five cases of necrosis of the epiphysis in 12 patients treated Schein (1967) has two cases of necrosis of the femoral head in four patients treated by manipulation Watson Jones (1946) reports 25 per cent Another method of treatment of slipping is open reduction In this form of treatment, a figure as high as 75 per cent has been reported for the risk of necrosis of the head of the femur (Schein 1967) We have empolyed a third treatment procedure in order to achieve reduction, viz forceful extension at the hip with the aid of traction on the tubercle of the tibia, and no development of necrosis of the head of the femur has been observed with this treatment Schein (1967) and Casey et al (1972), in treatment of three and twelve patients respectively, likewise found no cases of necrosis of the head following traction treatment

After reduction, the epiphyseal head must be immobilised by fixation until the epiphyseal line has disappeared, using one or another form of osteosynthesis Thin Kirschner wires are considered most suitable for this, as more massive osteosynthesis material might push the head away from the neck, thereby increasing the risk of traumatising the blood supply to the head, resulting in necrosis of the head (Schein 1967) With regard to late results, Fahey & O'Brien (1965) report satisfactory results in ⅔ of their patients after manipulation or traction followed by internal fixation, the period of observation varying from 2 to 16 years In the material of Barash et al (1971), ¾ of the results were satisfactory after manipulation or traction plus fixation Their material comprises eight patients with a period of observation of from 2 to 8 years In evaluating late results, it must be taken into consideration that the various series are small, and that the periods of observation are often relatively short

In the present material, with a period of observation of from 2 to 12 years, roentgenologically normal conditions were found in three out of eight patients and four of the eight patients had slight to moderate deformation of the neck and head of the femur, changes which may lead to the development of degenerative arthritis on account of the altered weight-bearing conditions in the hip joint One of the eight patients had pronounced degenerative arthritis

With a view to avoiding the development of necrosis of the head of the femur, the results of the present study and the review of other materials would appear to suggest that the treatment of choice is traction (Schein 1967, Casey et al 1972)

## SUMMARY

The results are reported of the treatment of eight cases of acute (traumatic) slipped capital femoral epiphysis, reduced by forceful traction on the tubercle of the tibia followed by drilling through with Kirschner wires No necrosis of the epiphysis developed among the eight cases In the light of these results this therapy is recommended in cases of acute slipping of the capital femoral epiphysis On the other hand, as far as the late complications are concerned, such as degenerative arthritis, the late results are probably no better than those obtained with other forms of treatment

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## MATERIAL AND METHODS

Our series comprises the patients operated on when we began to use HTO in treating gonarthrosis It comprises 89 patients operated on between 1965 and 1971 The operations were carried out by 10 surgeons with varied operative experience Of the [illegible] patients 86 were available for postoperative examination, one patient was excluded (fully satisfied patient with anchylosis of the knee following infection) Of the remaining [illegible] patients 11 of the osteotomies were bilateral giving a total of 96 knees reexamined Five patients had a second operation on the same leg (two for delayed healing three because satisfactory correction had not been obtained) The figures given throughout the paper refer to the definitive state and number of knees and not to the number of operations or patients

The indication for osteotomy was a combination of deformity with roentgenological signs of arthrosis of the knee and failure to relieve pain by the usual conservative means There were 79 knees with varus deformity and 17 knees with valgus deformity The average age was 64 years ranging from 37 to 80 years Compared to the sex distribution of the population in our admission area there was a significant over-representation of women in our series especially in patients over 60 years The exact duration of knee pain was impossible to estimate precisely but was never shorter than 2 years The follow up period varied between 15 and 84 months with an average of 38 months

### *Preoperative assessment*

Preoperatively the knee were assessed in terms of four basic parameters pain stability range of motion and functional capacity The degree of deformity was assessed from weightbearing anteroposterior roentgenograms in 62 knees and non weightbearing roentgenograms in 34 knees

There were 48 knees with varus deformity of up to 5 degrees 19 knees with the deformity up to 10 degrees and 12 knees with the deformity over [illegible] degrees In 17 knees with valgus deformity the deformity ranged from 12 to 25 degrees Of the 79 knees with varus deformity 72 had an arc of motion exceeding 80 degrees and seven had an arc of motion ranging from 65 to 80 degrees Fifty six knees were without contracture 19 had a contracture ranging from 5 to 15 degrees and four had a contracture ranging from 16 to 25 degrees Contracture of more than 25 degrees was considered a contraindication for HTO In 17 knees with valgus deformity there was one knee with an arc of motion of 60 degrees two knees with motion ranging from 65 to 80 degrees and 14 with motion exceeding 80 degrees Two of them had a contracture of [illegible] degrees and one a contracture of 25 degrees Of the 79 knees with varus deformity there were [illegible] knees with clinical signs of instability but only 39 knees with roentgenological signs of subluxation Of the 17 knees with valgus deformity 10 knees experienced clinical instability and only four knees had roentgenological signs of subluxation Angular deformity and subluxation were measured on roentgenograms according to the suggestions of Ahlbäck 1968 but no attempt was made to estimate the severity of arthrosis

### *Technique of operation and postoperative management*

A bone wedge with a lateral or medial base was removed from the upper part of the tibia proximal to the patellar tendon insertion The size of the wedge was calculated

Acta orthop scand 46 996–1007, 1975

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# FACTORS INFLUENCING RESULTS OF HIGH TIBIAL OSTEOTOMY IN GONARTHROSIS

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Accepted 10 v 75

Despite the postulated association between knee pain, roentgenological degenerative changes and proven angular deformity (Danielsson & Hernborg 1970), the predictability of progression of subjective inconvenience for a given patient who suffers from gonarthrosis cannot be made with sufficient certainty Spontaneous decline of subjective complaints in patients with arthrotic knees is an occurrence very well appreciated in daily orthopaedic practice

High tibia osteotomy (HTO) has become a very common method in the treatment of gonarthrosis, with a relatively constant success rate reported (Appel & Friberg 1972, Bauer 1969, Debeyre & Artigou 1972) Since there is no reliable system for classifying the evolutionary phase of gonarthrosis, it is impossible to reject the hypothesis that reported deterioration may be the result of some self-deteriorating factor acting in gonarthrosis There are two theoretical explanations for development and progress of gonarthrosis The theory of biomechanical causes (Pauwels 1965) and the theory of circulation disturbance (Arnoldi 1971) The HTO may act by changing the mechanical axis of the knee, by altering the circulation or by both Despite this discussion, we believe that very little attention is paid to the causes for the patient's satisfaction or dissatisfaction with HTO

In our retrospective study we tried to investigate the following Whether or not the patient's satisfaction after HTO is correlated to the functional state of the operated knee We were further interested in which other factors influence the patient s assessment of HTO

*Table 1* Subjective and objective assessment of results in 96 knees with high tibia osteotomy (HTO)

| | Deformity | | Total |
|---|---|---|---|
| | Valgus | Varus | |
| *Subjective* | | | |
| Satisfied | 36 | 4 | 40 |
| Improved | 27 | 5 | 32 |
| Poor | 16 | 8 | 24 |
| | | | 96 knees |
| *Objective* | | | |
| Excellent | 41 | 2 | 43 |
| Good | 20 | 4 | 24 |
| Poor | 18 | 11 | 29 |
| | | | 96 knees |

*The durability of results*

We have related the operative results to the length of the follow up period Two groups of knees were compared in the first group which comprised 58 knees, less than 3 years have passed since the operation In the second group which comprised 36 knees more than 3 years have passed We compared the proportion of excellent, good and poor results (according to demerit point scheme) in both groups It appeared that the results did not differ in the two groups concerned ($0\ 95 > P > 0\ 90$) But the conclusion that improvement once gained, lasts more than 3 years is not fully justified, for the mean observation time in the groups of fully satisfied and improved patients was only 2 8 years as compared with 3 7 years in the poor group

*The influence of preoperative deformity*

*a) The type of deformity* The results of HTO done for valgus deformity are strikingly worse both subjectively and objectively as compared with knees with varus deformity (Table 1) Several interrelated factors seem to influence the results of HTO done for valgus deformity 1) concurrent joint disease which influences the mechanics of the knee joint was present in half of these knees (seven cases of hip disease and one case of contralateral knee fusion in 15 patients), 2) the ligament laxity which is primarily more pronounced in valgus knee, is further accentuated by the operation procedure (Shoji & Insall 1973) The

from the preoperative femorotibial angle As mentioned above only *two-thirds of* the measurements were made on a standing roentgenogram In the present series tightening of the ligamentous structures was noticed in operative records of seven knees operated for varus deformity and in one knee operated for valgus deformity Postoperatively the knee was immobilized in a cylindrical cast for 4 8 weeks and weightbearing was encouraged as early as possible *usually within 1 week after* operation

### *Method of follow up study*

The goal was to gain a very accurate description of the patient s own assessment of the operative result as a contrast to the objective evaluation of the knee made at the same time by us All patients were interviewed personally by the authors and as *a result of this interview the patient was asked to make his own assessment of* the effect of operation using the following grading a) fully satisfied b) improved c) no change d) worse No change and worse are throughout the paper reported as poor

In the objective evaluation which was based on the grading system of Potter *(1972) the following features were measured in demerit points (DP)*

A Subjective features pain (0 7 DP) walking support (0–4 DP) walking distance (0 4 DP)

B Objective features Restriction of motion (0–6 DP) contracture (0–6 DP) angular deformity in standing position (0–4 DP) instability (0–4 DP) and *quadriceps power (0 6 DP) Using the demerit points the results were grouped as* follows excellent results (0–3 DP) good results (4–7 DP) fair and poor results (> 7 DP)

## RESULTS

Summarized results in Table 1 show that the patients tended to over *estimate the results in comparison to the results of the objective* evaluation In searching for the influence of age on the results it was appar *ent that this tendency to overestimate* was more pronounced in patients over 65 years of age (Subjectively 49 per cent fully satisfied as com pared to only 25 per cent excellent objective results in this age group ) Less demand for mobility in the older people can be accepted as an explanation of this fact but the patient s devotion to his surgeon should be also considered (We were careful in our follow up not to let the operating surgeon interview his own patient )

The influence of sex the percentages of excellent objective results were equal in both sexes (43 per cent in women and 45 per cent in men) The percentage share of subjectively fully satisfied patients *in* the female group was twice as high as in the male group (49 per cent and 27 per cent respectively) *It seems as though the younger men are* more critical in considering the state of the knee

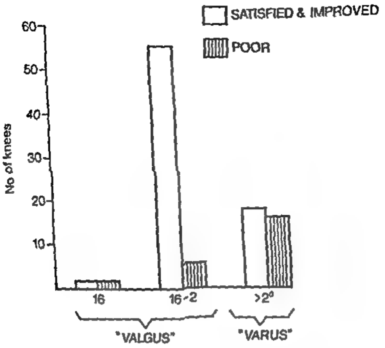


*Figure 2 Subjective assessment × definitive angle*

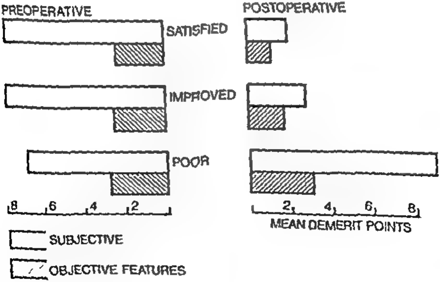


*Figure 3 Changes in knee state by operation (expressed in means of demerit points) in three groups of patients*

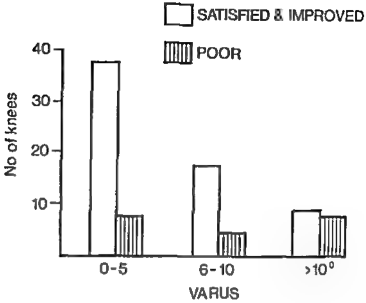


*Figure 1 Subjective assessment × initial angle*

close association of instability with progress of gonarthrosis has been demonstrated (Bauer 1969)

*b) The grade of preoperative deformity* Figure 1 relates the preoperative deformity in varus knees to the assessment made by the patient It appears from the Figure that osteotomy is unlikely to satisfy patients with severe varus deformity Several reasons for failure may be considered 1) The deformity in these knees coincides with a greater degree of ligament laxity The difficulty in such cases is in deciding how large a bone wedge should be removed to correct a fixed deformity and what allowance should be made for joint instability Undercorrection is, in fact, closely correlated to the recurrence of deformity (Figure 5) 2) There exists the possibility that such a great degree of deformity is an expression for a special, more progressive form of gonarthrosis which cannot be stopped by HTO

*c) The success of correcting the deformity* Figure 2 correlates the definitive femorotibial angle with the satisfaction of the patient It is apparent that the success is dependent on the possibility of correcting the angular deformity and returning the mechanical axis to the centre of the knee joint One difficulty is in determining which is the value for the "physiological" valgus of the femorotibial angle when correcting the deformity, the other one is in defining this angle in the follow-up study It is obvious that these two values are entirely different, which makes the comparison of published results difficult We used Bauer's

was done despite the development of osteophytes in the majority of knees sometimes to a considerable size

*Recurrence of deformity*

This was our most frequent complication observed in a total of 26 knees with primary varus deformity and in nine knees with primary valgus deformity (overcorrection) making a total of 35 knees with definitive varus deformity The deformity was slight (up to 2 degrees of varus) in 20 knees and total recurrence was observed in 11 knees There was no correlation with age and sex of patients uncertain correlation with operative method (fibulaosteotomy versus lysis of upper fibulotibial joint) On the contrary there were close correlations to the initial femorotibial angle (Figure 4) and to the degree of correction of the deformity (Figure 5) in the group of knees with primary varus deformity The relations to the initial angle were discussed above but the correlation to the correction achieved by operation deserves mention here We have observed in some patients that there is a loss of correction into varus already during the period of healing In the normal knee joint there is a varus stress during the stance phase of gait (Smidt 1973) and it is reasonable to assume that it still was present after the tibial osteotomy in the patients whose deformity was not fully corrected The unsatisfactory mechanical qualities of the medial tibial condyle in arthrosis (Lereim & Goldie 1973) are further deteriorated by osteotomy It is difficult if not impossible to relieve with a cylindrical cast the varus stress still acting in an undercorrected knee with osteotomy particularly when the patient is obese This also explains (in Figure 5) why there are no recurrences of the deformity in primary overcorrected knees Bilateral operations in seven patients maintained primary correction in both knees in three patients the correction was lost in both knees and in only one case was the correction maintained in one knee and lost in the other (this knee was successfully reoperated later) This fact encouraged us to investigate whether there are some anatomical forms of deformity in the tibial head which are coupled with the recurrence of deformity Two main types of deformity in the tibial head could be discerned in gonarthrosis with varus deformity a) the type where deformity is caused by reduction of the medial tibial condyle b) the type where the deformity is caused by increased varus angle between tibial head and the tibial shaft (Figure 6) In the 48 knees in which the primary varus deformity was less than 5 degrees

scheme (1969) defining the angle from 2 to 16 degrees of valgus as "physiological" in our follow-up study It is obvious that there is a group of satisfied patients in spite of their persistent deformity The observation time in this patient group is no different from the mean observation time of patients with well corrected deformity, indicating long-lasting osteotomy effects despite undercorrection in this small group

*d) The effect of subluxation* We did not succeed in finding any fully satisfied patients with persistent roentgenological signs of subluxation in the group of patients in whom HTO had been done more than 3 years previously We consider now that roentgenological subluxation combined with femorotibial *angle values exceeding 10 degrees* contraindicate HTO and that alternative procedures such as knee fusion or replacement are preferable in these patients

### *The influence of preoperative state*

Figure 3 relates changes in the state of the knee made by operation to the patient's own assessment One should notice The reasons for patient satisfaction were *primarily* subjective features, and the objective state of the knee is not so much influenced by the operation We judged the state of the knee on the basis of demerit points and the possibility should be considered that the evaluating scheme was not sensitive enough

### *The correlations with roentgenological signs*

All roentgenograms both pre- and postoperatively were evaluated in terms of the following parameters sclerosis and narrowing of medial and lateral and femoropatellar joint space, flattening of femoral condyles, reduction of tibial condyles and subluxation No notice was taken of osteophytes No attempt was made to grade the changes, instead, only pure comparisons were made using the terms unchanged (amalgamated plus ameliorated) and worse It appeared that there exists some correlation between progression of roentgenological changes and the patient's own satisfaction *with the results of HTO* In the group of satisfied and improved knees roentgenological signs of deterioration were present in 18 per cent and in the poor group deterioration was noticed in 45 per cent of the knees There is one exception the femoropatellar arthrosis progressed equally in both groups In fact, there was only one patient in the whole series in whom patellectomy

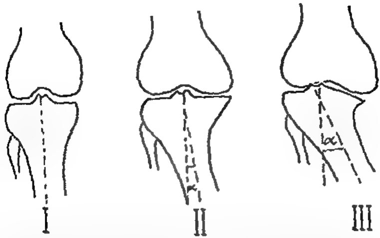

*Figure 6 Types of tibial deformity in gonarthrosis I the normal knee joint, II the knee joint where the tibiofemoral deformity is caused by increased angle between tibial head and shaft, III the deformity is a combination of increased angle head-shaft and reduction of medial tibial condyle*

again that there exist two types of gonarthrosis The one type is characterized by moderate degree of angle between tibial diaphysis and epiphysis, absence of reduction of medial tibial condyle, absence of signs of subluxation In these knees the tibiofemoral angle does not exceed 10 degrees and the chances of satisfying the patient by performing an HTO are high The other type is roentgenologically characterized by combination of reduction of medial tibial condyle (the angle between tibial head and shaft exceeding 9 degrees), presence of roentgenological signs of subluxation, and the femorotibial angle exceeds 10 degrees The correction of the deformity in these knees is very difficult, recurrence of the deformity is frequent, and the chances of satisfying these patients by doing an HTO are low We cannot decide if the type with poor prognosis is a special type caused, for example, by osteoporosis (Debrunner 1961) or if it represents only the late development of the former one

*Complications*

The only other complication influencing subjective assessment was infection in two knees this was the supposed cause of recurrence of the formity This solitary statement was made for knees with valgus deformity by Shoji & Insall (1973), and in a more general form by Coven-assessment

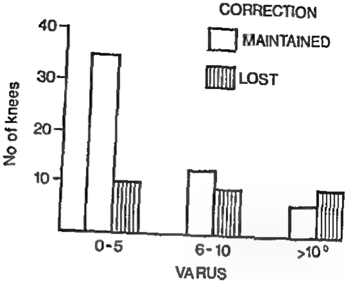


*Figure 4 Initial angle × definitive correction The abscissa gives the degree of preoperative femorotibial angle*

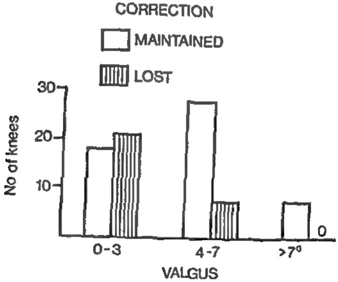


*Figure 5 Immediate postoperative correction × final correction The abscissa gives the degree of immediate postoperative femorotibial angle Measured on weight-bearing roentgenogram*

there was no noticeable reduction of medial tibial condyle, and the mean angle ($\alpha$ in Figure 6) between tibial head and shaft was 4 7 degrees In 12 knees in which the deformity exceeded 10 degrees of varus, both reduction of medial tibial condyle and increase of head-shaft angle (mean $\alpha$ angle 9 2 degrees) were seen This permits the suggestion

HTO done for gonarthrosis and the correction of femorotibial deformity

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*Key words* arthritis surgery knee osteotomy tibia

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## DISCUSSION AND CONCLUSIONS

HTO is an analgetic operation causing very few changes in the objective state of the knee beyond correcting the tibiofemoral deformity On reading several reports on this object, one gains the impression that, provided that the right correction is done, good results are achieved in a high proportion of all operated knees

Only rarely does one meet the suggestion that HTO is not the appropriate operative method in all types of gonarthrosis combined with deformity This solitary statement was made for knees with valgus deformity by Shoji & Insall (1973), and in a more general form by Coventry (1973) Debeyre & Artigou (1972), on the basis of 260 HTO, stated that the absence of subluxation signs is essential for good results with HTO, while the correction of the deformity is of secondary importance in all types of gonarthrosis However, the degree of ligamentous instability and subluxation that can be accepted without prejudicing the results of osteotomy is hard to define in these reports In a recent report on follow-up of knees where HTO was done more than 5 years previously, Insall (1974) observed that knees with more than 10 degrees of varus deformity are poor candidates for HTO We think that these observations are in accordance with our results, and indicate that there are two forms of gonarthrosis primary which are not suited for HTO The group of knees with valgus deformity caused by secondary biomechanic changes in other joints (hip, contralateral knee), and the group of knees with varus deformity exceeding 10 degrees and with typical changes in the medial tibial condyle The subjective assessment is influenced by secondary features such as age and sex, and even modest objective results are accepted as fully satisfying by the female patients in the age group over 65 years of age

## SUMMARY

Based on our results with high tibia osteotomy for gonarthrosis in 96 knees, the type of primary deformity was found to significantly influence the patient's subjective assessment of the results Knees with valgus deformity secondary to changes in other joints are not suitable for correction by HTO Knees with varus deformity exceeding 10 degrees and with roentgenological signs of reduction of the medial tibial condyle are seldom corrected by HTO and the results in these knees are poor There is a clear correlation between patient's satisfaction with

HTO done for gonarthrosis and the correction of femorotibial deformity

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## SUMMARY

Based on our results with high tibia osteotomy for gonarthrosis in 96 knees the type of primary deformity was found to significantly influence the patient's subjective assessment of the results. Knees with valgus deformity secondary to changes in other joints are not suitable for correction by HTO. Knees with varus deformity exceeding 10 degrees and with roentgenological signs of reduction of the medial tibial condyle are seldom corrected by HTO and the results in these knees are poor. There is a clear correlation between patient's satisfaction with

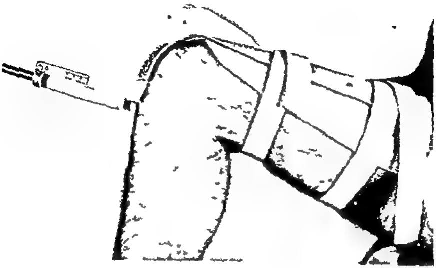

*Figure 1 Apparatus in position for measurement*

*Table 1 Age and sex distribution of the examined subjects*

| Age | 10–20 | 21–30 | 31–40 | 41–50 | 51–60 |
|---|---|---|---|---|---|
| Males | 5 | 5 | 5 | 5 | 5 |
| Females | 5 | 5 | 5 | 5 | 5 |

## RESULTS

The mean sagittal instability for different age groups and for the two sexes is given in Table 2. The values were slightly greater for males than for females, but the difference is not significant. The sagittal instability increased with age for both sexes, and the difference between the means for the sexes is significant ($P < 0.005$). The mean sagittal instability was somewhat less than 5 mm (range 1–10 mm). The mean difference between the greater and the smaller values for the two knees was about 1 mm (Table 3).

The implications of these figures for a differential diagnosis may be judged on the following basis. A difference exceeding 2.5 mm would be expected in five subjects out of 100 of a normal material, a difference of more than 4.2 in one out of 1000. The calculation is based on five

Acta orthop scand 46 1008 1011 1975

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# A MORE EXACT MEASUREMENT OF THE SAGITTAL STABILITY OF THE KNEE JOINT

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Accepted 30 vi 75

For a more objective evaluation of injuries to the anterior cruciate ligament the ordinary clinical test for sagittal instability of the knee joint is used In this technique the examining physician positions himself in front of the knee so that the displacement of the knee joint occurs towards him, but it is then difficult to estimate the extent of the displacement A better arrangement is to have one person pull on the *knee while another stands at the side of the knee and observes the for* ward displacement This is done for both knees and a comparison of them is then made Even with this method it is difficult to measure the true difference in the sagittal mobility, and a number of more objective techniques have been worked out Volkov (1971) designed a device with which he could measure the sagittal instability in linear units (millimeters), and another method has been reported by Ken *nedy (1971)*

## MATERIAL AND METHODS

At the Department of Orthopaedics Regional Hospital Linkoping a special apparatus for this purpose has been in use for a number of years it was designed by O Lindahl with the collaboration of E Raeder an engineer The apparatus which is shown in Figure 1 consists of a curved metal plate of large area which is placed on the surface of the thigh Supported on the tibial tuberositas is a freely sliding sphere whose displacement can be measured on a scale The accuracy of this *technique* was examined as follows

On 50 subjects with sound knees 5 measurements of the sagittal instability of the knee joint were performed on each knee making a total of 500 measurements The subjects were patients who had sought advice for ailments not involving the legs or knees and who had stated on questioning that they had sound knees with no history of trauma The age and sex distributions are shown in Table 1

the difference between the two knees was never more than [illegible] millimetre or so. This difference is thus considerably more significant than the value for the individual knee. For a group of patients undergoing operations at this department for rupture of the anterior cruciate ligament the sagittal instability ranged from 0 to 12 mm, while the difference between the knees was never less than 5 mm. The advantage of this method, which differs from that used hitherto only in respect of the actual grading of the sagittal instability, is that besides giving a more exact measurement it also gives the difference between the knees, a measurement that is a considerably more reliable measure of the instability than is the value for the relevant knee joint.

In a further study an examination will be made of the correlation between postoperative sagittal instability of the knee joint and a subjective feeling of instability of the knee.

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*Key words*: knee joint; sagittal instability; measurements; cruciate ligament injuries

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determinations on each knee It is also assumed that the values are normally distributed, it would be noted that the limiting values 2 5 3 3 and 4 2 mm are only estimates obtained from the material presented in this study The reproducibility of the method was examined by having five investigators each perform three measurements on the same knee Each investigator reported the same values for all three measurements, two recorded 5 mm and three 4 mm To obtain an impression of how complete muscular relaxation affects the sagittal instability of the knee joint, measurements were also performed on 10 subjects before and after inducing general anaesthesia There was no notable difference in the magnitude of the instability

*Table 2 Magnitude of sagittal instability mean values for the age and sex groups*

| Age | 10–20 | 21–30 | 31–40 | 41 50 | 51–60 | 10–60 |
|---|---|---|---|---|---|---|
| Males | 4 24 | 5 00 | 4 90 | 4 80 | 6 78 | 5 14 |
| Females | 3 02 | 4 44 | 4 80 | 3 94 | 5 12 | 4 25 |
| Both sexes | 3 63 | 4 72 | 4 85 | 4 37 | 5 95 | 4 70 |

*Table 3 Difference in sagittal instability of the two knees mean values for the age and sex groups*

| Age | 10–20 | 21–30 | 31 40 | 41–50 | 51 60 | 10–60 |
|---|---|---|---|---|---|---|
| Males | 0 96 | 0 88 | 1 16 | 1 52 | 1 00 | 1 10 |
| Females | 0 60 | 1 12 | 0 96 | 1 08 | 0 88 | 0 93 |
| Both sexes | 0 78 | 1 00 | 1 06 | 1 30 | 0 94 | 1 02 |

## DISCUSSION

Although the usual method for estimating the anterior sagittal instability of the knee joint has obvious shortcomings great importance is still ascribed to it in the diagnosis and in the evaluation of the results after reconstruction of the cruciate ligaments (Gillquist et al 1971) Results with fairly exact measurements have been reported For instance, Volkow found that a sagittal instability of more than 10 mm is indicative of damage to the anterior cruciate ligament Using a more complex method, Kennedy found that the sagittal instability of the knee joint in a group of 115 athletes ranged from 0 to 5 mm In the present study in normal subjects values between 1 and 10 mm were found, but

*Figure 1 Boy 16 years old with the characteristic recurvation deformity of the upper end of the tibia*

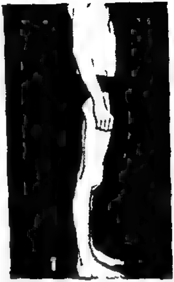

*Figure 2 a The left knee of a 16 year old girl showing the forward tilting of the upper tibial joint surface and the atrophy of the tibial tuberosity 5 years after tibial wire traction*

Radiograms showed in all cases a forward tilting of the upper tibial joint surface (Figure 2, a and b) The anterior angle between the joint surface and the longitudinal axis of the tibia was reduced from the normal 93 97° (von Lanz & Wachsmuth 1938) to 71–85° Moreover, in all cases a marked atrophy of the tibial tuberosity region had occurred A premature fusion of the anterior part of the epiphyseal plate of the affected knee was observed in patients with an epiphyseal plate which was still visible (Figure 3 a) The tilting increased with growth

Acta orthop scand 46, 1012–1019, 1975

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# GENU RECURVATUM

## *A Late Complication of Tibial Wire Traction in Fractures of the Femur in Children*

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Accepted 7 iii 75

**Genu recurvatum developing as a late sequela after tibial traction has scarcely been mentioned in the literature reviewed The purpose of the present paper is to draw attention to this late complication by referring to several cases treated over the past ten years**

### MATERIAL

The material consists of seven cases five boys and two girls who had been treated for fracture of the femoral shaft, three on the right side and four on the left side The relevant data are given in Table 1

The age of the patients when the fracture occurred varied between 9 and 14 years Wire traction was used for 10 to 14 weeks, the duration of the traction being unknown in one case Complications developed in five of the cases One had a severe infection which delayed union and led to a 5 6 cm shortening of the femur In two cases angulation occurred and corrective osteotomies were performed 10 and 20 months after the accident respectively Furthermore, two patients slipped and re fractured when allowed up on crutches

In none of the cases is there any information of early complications due to the wire During the first few years following the fracture and wire traction, all but the youngest patient developed symptoms in the knee region, viz pain, fatigue weakness or impaired function

### RESULTS

On clinical examination a characteristic recurvation deformity of the upper end of the tibia was found in all cases (Figure 1) A distinct increased extension mobility was observed in the knee joint, and the flexion mobility was somewhat reduced as compared with the normal side A slight increase in the valgus of the knee joint was apparent in five of the cases Leg shortening was found in all cases, both in the femur and in the tibia

*Table 1 Survey of seven cases of genu recurvatum treated in Sophies Minde Orthopaedic Hospital (SMOH)*

| | Case 1 | Case 2 | Case 3 | Case 4 | Case 5 | Case 6 | Case 7 |
|---|---|---|---|---|---|---|---|
| Age (years) when fracture occurred | 11 | 10 | [illegible] | 13 | 9 | 14 | 9 |
| Duration of wire traction (weeks) | 12 | 12 | 14 | 10 | unknown | 12 | 12 |
| Age when admitted to SMOH (years) | 16 | 20 | 16 | 21 | 16 | 34 | 11 |
| Hyperextension mobility (degrees) | 25 ( 5)* | 20 ( 5) | 25 ( 3) | 25 ( 5) | 15 ( 5) | 15 ( 5) | 15 ( 5) |
| Flexion mobility | 145 (170) | 125 (150) | reduced 10 | reduced 10–15 | 135 (135) | unknown | unknown |
| Tibial level angle | 75 ( 98) | 73 ( 94) | 71 (93) | 77 (94) | 75 (92) | 85 (94) | [illegible] (93) |
| Tuberosital atrophy | + | + | + | + | + | + | + |

* Figures applicable to the normal side are given in brackets

*Figure 2 b The normal right knee of the same patient*



*Figure 2 c The left knee after corrective osteotomy*

traction through the proximal end of the tibia, over a period of several weeks. The forward tilting of the joint surface of the tibia indicates that the deformities have been caused by premature closure of, or by retarded growth within, the anterior part of the epiphyseal plate. This view was also confirmed by the observation of a premature ossification of the epiphyseal plate of the affected knee in patients with still visible epiphyseal plates.

When considering the possible mechanism of such a growth disturbance it should be emphasized that the anterior part of the epiphyseal growth plate runs distally beneath the tibial tuberosity (Figure 3 b). Within the latter a tongue like projection of the ossified area of the proximal epiphysis is seen during childhood from eight years onwards, occasionally also an additional centre of ossification appears within the tuberosity. The tongue shaped process of the tibial epiphysis and the separate ossicle fuse to the metaphysis, normally at the age of 15 in girls and at the age of 18 in boys (Flecker 1942). The anterior part of the growth plate can therefore be damaged if a traction wire is placed too close to the tibial tuberosity, it being a well known fact that such wires easily migrate some distance during traction.

It might be inferred that a traction wire would most likely damage only a small part of the growth plate underneath the tibial tuberosity. Hence also the growth disturbance would very likely be located only in the lower part of the epiphyseal region and not give rise to severe angular deformation of the tibia. It has been reported, however, that angular deformation may occur when the growth plate underlying the tibial tuberosity is fused prematurely and spontaneously as a result of Osgood Schlatter's disease (Stirling 1952, Jeffreys 1965). A similar deformity may also develop following transplantation of the tibial tuberosity in children with recurrent dislocation of the patella (Heywood 1961).

It has been shown experimentally that curetted or drilled defects of an epiphyseal plate are likely to be repaired by bone. The transepiphyseal bone plug thus formed connects the epiphysis to the metaphysis. The cartilage cells of the uninjured part of the growth plate continue to proliferate for some time but finally the proliferation ceases and even the adjacent part of the growth plate is replaced by bone in the same way as during fusion of epiphyseal plates by means of staples. The final cessation of the proliferation of the cartilage cells has in such cases been ascribed to increased pressure within the cartilage which is created by the fixation of the epiphysis to the metaphysis (Siffert

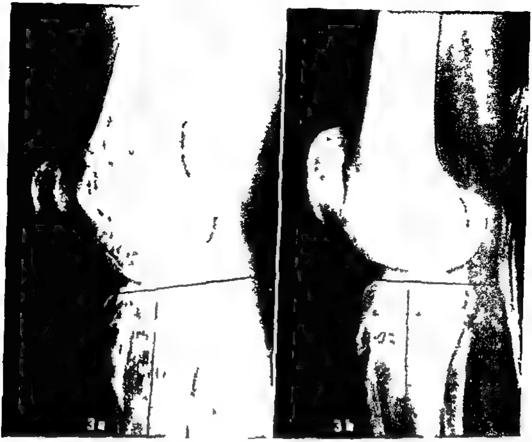


*Figure 3 a The right knee of a boy 14 years old treated with tibial wire traction 2 years earlier The epiphyseal plate is closed beneath the tibial tuberosity but is still visible in the posterior part*

*b The x ray of the normal left knee of the same patient shows the anterior part of the epiphyseal growth plate running distally beneath the tibial tuberosity*

A wedge osteotomy (Figure 2 c) was carried out in the upper part of the tibia in six cases in order to re establish the normal tibial level angle To minimize limb shortening a wedge of homologous bone was inserted anteriorly in five cases and in one case a dorsal wedge was removed The osteotomy was secured with staples or plates The final clinical and radiographical result has been satisfactory in all cases The bowed tibia of the latest patient recently admitted at an age of 11 years will presumably have to be corrected in the future

## DISCUSSION

The seven cases of genu recurvatum reported here were all observed in patients who had been treated at the age of 9 to 14 years with wire

the tibial tuberosity Where tibial wire traction is used in children it is advisable to insert the wire distal to the tuberosity

*Addendum*

Since this report was written a similar case with bilateral knee recurvation has been treated in this hospital

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*Key words* genu recurvatum tibia children, fractures

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1956) Hence it seems reasonable that a fusion between only some parts of the apophysis of the tibial tuberosity and the metaphysis, caused by damage to the underlying growth plate by a migrating traction wire, would also result in a premature ossification of the adjacent parts of the epiphyseal plate This could be the mechanism involved in the development of the recurvation deformities reported here

Other pathogenetic mechanisms might be suggested Thus local infection, although it is a relatively infrequent complication of wire traction (Dencker 1964), could at least be a contributing factor in the development of the growth disturbances However, no sign of infection around the wire has been observed in the cases reported here Furthermore, the epiphyseal plate is resistant to infection, and growth is not usually disturbed by infection on the metaphyseal side of the plate (Siffert 1957)

Premature fusion of the proximal tibial epiphysis has been observed following longlasting immobilization in tuberculosis of the hip (Gill 1944, Parke et al 1949) However, such fusion, which in most cases is central and does not lead to recurvation of the knee, is unlikely to occur unless the period of treatment exceeds 2 years (Parke et al 1949) Hence the immobilization alone can hardly be held responsible for the deformities following tibial wire traction, although five of the reported cases had been immobilized for some time in addition to the traction period

Genu recurvatum frequently gives rise to considerable complaint Accordingly our patients also suffered from pain, instability and weakness of the affected knee joint, and in six of the seven patients these complaints justified corrective osteotomy of the tibia Recurvation of the knee may also cause development of osteochondritis dissecans (Smillie 1962) and osteoarthritis Although this deformity probably is a relatively uncommon complication of tibial wire traction, the serious complaints to which it may lead indicate that care should be taken to ensure that the wire is placed distal to the tibial tuberosity, when such traction is applied in children

## SUMMARY

Seven cases of genu recurvatum following wire traction through the proximal end of the tibia in children treated for fractures of the femur are reported A premature closure of the anterior part of the growth plate was most probably caused by too close a proximity of the wire to

*Figure 1 Long spiral fracture of the tibia with a shortening of about 2 cm without fracture of the fibula*

in addition a peroneal nerve palsy The fracture was fixed in plaster and after ■ weeks the patient was transferred to us for continued ambulatory treatment Examination revealed that there had been no improvement in nerve function the nerve still being fully paralysed The position of the tibial fracture was stable but because the tibia had shortened while the fibula had remained whole it was decided to take further x rays of the knee in the hope that a fracture of the fibula had been overlooked The x ray disclosed superior and lateral dislocation of the head of the fibula in such a way that the proximal part of the head was on a level with the right knee joint space (Figure 2 a b) Following this finding the patient was admitted to our Department for operation

At operation the head of the fibula was seen to exert direct pressure on the peroneal nerve causing it to bend distinctly The colour of the nerve was bluish for a few centimetres and remained so even after its

Acta orthop. scand. 46, 1020–1025, 1975

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# PERONEAL NERVE PALSY DUE TO SUPERIOR DISLOCATION OF THE HEAD OF THE FIBULA AND SHORTENING OF THE TIBIA

*(Monteggia-like Fracture Dislocation of the Calf)*

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Accepted 28.iv.75

This article describes a case of peroneal nerve palsy due to proximal dislocation of the head of the right fibula. The dislocation occurred as a result of a long spiral fracture of the tibia with resultant shortening of the tibia of approximately 2 cm and consequent proximal dislocation of the upper tibio-fibular joint.

Isolated dislocation of the head of the fibula with no further traumatic injury to the tibia has been described many times in the literature. Particularly common is the antero-lateral dislocation, while the proximal dislocation is extremely rare. In Ogden's review of 43 cases (1974) there is only one similar case, and that too was discovered about 7 years after the injury. To the best of our knowledge no case with the above characteristics has yet been described in the English literature, i.e. long spiral fracture of the tibia causing shortening of that bone and proximal movement of the head of the fibula with no other fracture. The resultant pressure on the peroneal nerve caused its paralysis.

This type of fracture is reminiscent of the one carrying Monteggia's name and, in view of the great similarity between the two, it is very tempting to call it Monteggia-like fracture dislocation of the calf.

## CASE REPORT

A 34-year-old man was admitted to hospital after having injured his right calf when, during a riding accident, both he and the horse fell and the patient's right foot was caught beneath the horse's belly. At hospital a long spiral fracture of the right tibia (Figure 1) was diagnosed and,

*Figure 1 Long spiral fracture of the tibia with a shortening of about 2 cm without fracture of the fibula*

in addition a peroneal nerve palsy The fracture was fixed in plaster and after 3 weeks the patient was transferred to us for continued ambulatory treatment Examination revealed that there had been no improvement in nerve function the nerve still being fully paralysed The position of the tibial fracture was stable but because the tibia had shortened while the fibula had remained whole it was decided to take further x rays of the knee in the hope that a fracture of the fibula had been overlooked The x ray disclosed superior and lateral dislocation of the head of the fibula in such a way that the proximal part of the head was on a level with the right knee joint space (Figure 2 a b) Following this finding the patient was admitted to our Department for operation

At operation the head of the fibula was seen to exert direct pressure on the peroneal nerve causing it to bend distinctly The colour of the nerve was bluish for a few centimetres and remained so even after its


*Figure 2 a b Proximal and posterior dislocation of the head of the fibula*

dissection from surrounding scar tissue (Figures 3 and 4) Because reduction was impossible by this time, the head of the fibula was excised

The tibial fracture healed with resultant shortening of more than 2 cm The nerve recovered partially, enabling satisfactory function of the peroneus longus and brevis, tibialis anterior and extensor digitorum longus

## DISCUSSION

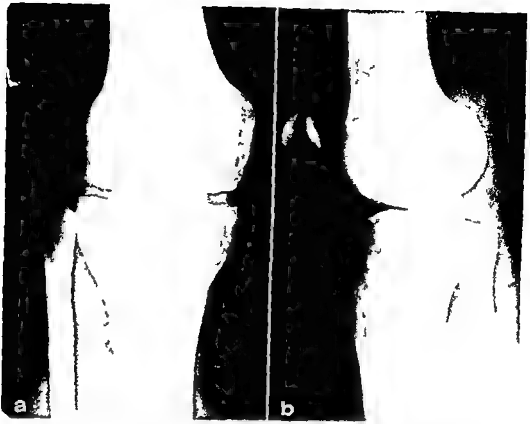
Acute isolated dislocation of the proximal tibio fibular joint is a rare injury, but one that has already been described by the following Lyle 1925, Vitt 1948, Dennis et al 1958, Christensen 1966, Clews 1968, Parkes et al 1973, Crothers 1973, and Ogden 1974

One common cause of this injury is parachute jumping (Vitt 1948, Dennis & Rutledge 1958, Crothers & Johnson 1973, Ogden 1974)

Lyle (1925), in a review of 36 cases, described three types of dis

*F gure 3 The pe oneal nerve was found compressed and d spla ed prox mally by the hea l of the f bula The t p of the surg cal shears po nts to the ca t lag nous s rfa e of the head of the f bula*

*F gure 4 The head of the f bula after release of the peroneal nerve*

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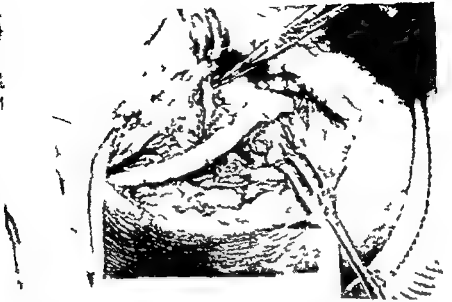

Figure 3 The peroneal nerve was found compressed and displaced proximally by the head of the fibula The tip of the surgical shears points to the cartilaginous surface of the head of the fibula

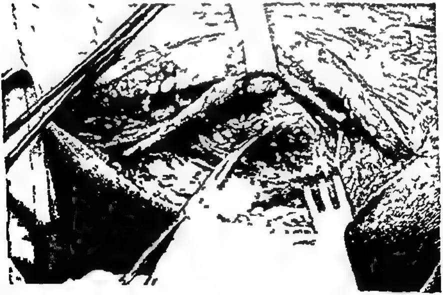

Figure 4 The head of the fibula after release of the peroneal nerve

location: 20 cases of anterior dislocation, 12 cases of posterior dislocation, of whom two had associated peroneal nerve lesions, and four cases of superior dislocation According to Lyle, the latter type cannot occur as an isolated injury, but instead occurs in association with fracture of the fibula or dislocation of the entire fibula, and always in conjunction with ankle injuries in which the fibular malleolus is displaced Lyle did not consider the possibility that shortening of the tibia could be due to fracture and superior dislocation of the head of a non-fractured fibula

Apart from two cases of peroneal nerve lesion associated with posterior dislocation (Lyle's review), one other case of peroneal nerve palsy in bilateral recurrent posterior dislocation has been described by Dennis (1958) In this case the dislocation was not caused by direct trauma To the best of our knowledge no case of peroneal nerve palsy in superior dislocation has as yet been described

In his review of 43 cases, Ogden (1974) pointed out that the most common type of dislocation is the antero-lateral one A breakdown of his series is as follows 10 cases of subluxation, 29 cases of antero-lateral dislocation, 3 cases of posterior dislocation, and only 1 case of superior dislocation

The last case is similar to ours, and was a 1-year old boy who fractured his tibia This healed with 1–2 cm of overriding and subsequent shortening After a lapse of 7 years he was seen because of a lateral "mass" which proved to be none other than the dislocated fibula head No treatment was undertaken

According to Ogden, one third of his cases had been overlooked initially Successful treatment of most cases consisted of closed reduction Only two cases required operation in one of them excision of the fibular head was performed, and in the second case arthrodesis of the joint was performed According to Ogden, since Lyle's series in 1925, the literature has contained reports of 75 cases of antero lateral dislocation, 3 cases of postero-medial dislocation, and 2 cases of superior dislocation

Despite the relative infrequency of superior dislocation, this possibility must be borne in mind, and particularly so in cases of post-traumatic peroneal nerve palsy

In our case, the diagnosis was missed, the knee not having been x-rayed There is no doubt that if the possibility of superior dislocation had been considered, prompt release of the peroneal nerve could have been effected by skeletal traction It would also have been possible to

obtain reduction of the head of the fibula and speedier and better recovery of the nerve. Three weeks of constant pressure upon the nerve could well have caused irreversible damage.

The purpose of this article is to record one other possible way of damaging the peroneal nerve, namely by superior dislocation of the proximal tibio fibular joint.

This form of injury—shortening of the tibia causing proximal dislocation of the fibula—resembles Monteggia's fracture dislocation of the forearm to such an extent that it is indeed tempting to call it Monteggia's fracture of the calf.


## SUMMARY

A case of peroneal nerve palsy due to superior dislocation of the proximal tibio-fibular joint is described. Emphasis is placed on the importance of early diagnosis and treatment.



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Key words: peroneal nerve palsy, fracture, dislocation, tibia, fibula.

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Acta orthop scand 46, 1026–1034, 1975

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# THE ARTERIAL SUPPLY OF THE TALUS

## *A Study on the Relationship to Experimental Talar Fractures*

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Accepted 24 xi 75

In a previous paper we described the arterial supply to the talus (Peterson et al 1974 a). We were able to confirm earlier findings (*Wildenauer 1950, Haliburton et al 1958, Mulfinger et al 1970*) The main arterial supply has been assumed to originate from the arteria canalis tarsi and from the arteria sinus tarsi (Wildenauer 1950, Mulfinger & Trueta 1970) In addition we observed numerous arterial connections between the tibial and talar marrow spaces by way of the *interconnecting capsule and ligaments Our study indicated* that the talus receives a great amount of arteries from many different sources, and its position is in the center of a large vascular net-work

In fractures of the talus, osseous necrosis may arise whether the fracture is displaced or not It has been stated that the greater the *displacement the higher the rate of necrosis (Hawkins 1970)* An occurrence of between 2 and 91 per cent has been reported (Coltart 1952, Hawkins 1970, Kenwright & Taylor 1970, Brinkmann et al 1973) In undergoing a necrosis a bone which has been deprived of its vascular supply will soon re-establish its circulation and a remodelling of bone will *occur (Phemister 1940, Haliburton et al 1958)* The necrosis is believed to be due to the deprivation of the blood supply, though the true pathogenesis is as yet not entirely clear (Hawkins 1970) The importance of the blood supply has indeed been demonstrated in some instances, e g when after a triple arthrodesis, by which the main arteries become destroyed, talar necrosis has developed This has been observed in not quite 10 per cent of cases (Marek & Schein 1945, Larsson et al 1961)

Despite being in the center of a rich vascular network it thus appears that the talus is sensitive to an alteration in its blood supply For this reason we have undertaken this investigation to study how experi-

mentally produced fractures of the neck of the talus might influence the arterial supply to this bone

## MATERIAL AND METHODS

The material consisted of 11 feet. Clinically there was no evidence of vascular disease nor of any other illness which might influence the vascular tree. The reasons for amputation were local bone and soft tissue tumors well away from the foot. The ages of the patients from whom feet were taken varied between 8 and 55 years. Seven specimens were obtained from people between 20 and 40 years of age.

The procedure of filling the arteries was exactly the same as in a previous study (Peterson et al. 1974 a), which in short was as follows: the arteries were filled with one part micropaque mixed with two parts 10 per cent formaldehyde solution. The injection was made under a constant pressure of 140 mmHg. The foot was placed in a bath with 10 per cent formaldehyde solution, and the infusion of contrast medium was carried on for 24 hours under the same pressure. The filling of the feet for this study was as satisfactory as for the previous one dealing with the analysis of the arterial supply. To facilitate the vascular analysis the feet were cut in sagittal sections 1.2 cm thick and studied by X-ray with transparencies obtained by the Spalteholz procedure (Peterson et al. 1974 a). Fractures were experimentally produced in the same way as has been described in a previous study (Peterson et al. 1974 b).

> The foot was placed in an ordinary shoe, to the sole of which two transversal steel bands were riveted firmly, one under the heads of the metatarsals and one under the heel. In those bands four rigging screws were attached and anchored to the stand by chains, two medially and two laterally. This gave full control of the inversion-eversion and the degree of dorsiflexion. It also gave possibility to apply varying pretension to the foot. The striking point and the direction of the pendulum was checked with X-ray in lateral and antero-posterior view and adjustments were made. Fractures of the talar neck were achieved by striking the sole of the foot with the pendulum at a given velocity and load.

For the present study the feet were first filled with the micropaque contrast medium and when X-rays had confirmed the satisfactory filling of the talus the experimental fractures were produced. It soon became evident that some difficulties arose in obtaining fractures with the same ease as in the previous study (Peterson et al. 1974 b). We interpreted this difficulty as being due to the formaldehyde preparation of the feet, which increased the elasticity of especially the soft but also the osseous structures (the consistency of the foot resembled hard rubber). Similar observations have been made by Moseley & Goldie (1963). In all feet where fractures were obtained, an analysis of the vessels was made on X-rays of the entire foot as well as of the individual sections. Further study was made on the individual sections after subjecting them to the Spalteholz procedure (Peterson et al. 1974 a).

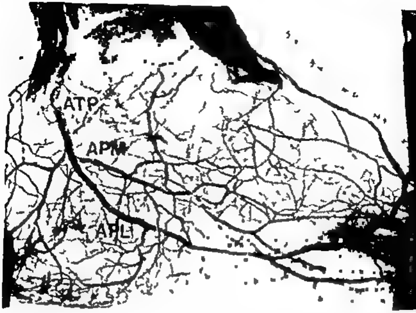


*Figure 1 a Angiogram of left whole foot from a 48 year old woman before production of fracture ATP = arteria tibialis posterior, APL = arteria plantaris lateralis, APM = arteria plantaris medialis The leakage of contrast medium seen at the top occurred during filling of vessels*

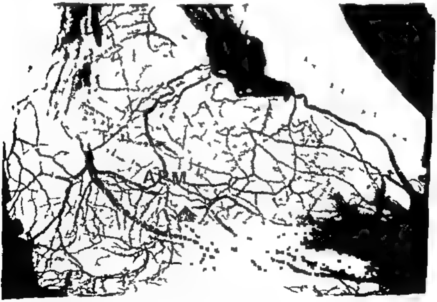


*Figure 1 b Same as Figure 1 a but after production of fracture without displacement Fracture line is marked by arrows There is now a defect in the filling of the arteria tibialis posterior corresponding to the talocrural and talocalcanear joints A localized defect is also seen in the arteria plantaris medialis (APM) marked by a large arrow and limited by the impact on the sole of the foot*

## RESULTS

Some difficulties arose in the interpretation of the course of the vessels in connection with the fracture There was a disarrangement of the arteries in and around the fracture Some vessels became stretched, others ruptured By comparing the X-rays before fracture with those after fracture it was possible, especially in the individual sections, to identify each vessel and its change of course and/or its disruption after fracture

### *Arteria tibialis posterior*

In four feet there was an interruption in the filling of this vessel behind the talus on a level with the talocrural and talocalcanear joint spaces (Figures 1 a & b) It was not evident that this was due to a rupture of the vessel, but there was a local disappearance of contrast probably due to compression In the remaining feet normal conditions prevailed

In the further course of the arteria tibialis posterior, after its division into the arteria plantaris medialis and arteria plantaris lateralis, it became evident that the impact load of the pendulum influenced the filling of the vessel Within an area corresponding to the limitations of the impact body on the footsole the contrast medium disappeared (Figure 1 b) from the arteria plantaris medialis without any signs of vascular rupture (There was no leakage of contrast medium outside the vessel ) The arteria plantaris lateralis was also affected in a similar way

### *Arteria canalis tarsi and arteria sinus tarsi*

The arteria canalis tarsi and arteria sinus tarsi are in the midst of the danger zone, and apparently disintegrate during the actual fracture process In all specimens the ascending branches from these arteries were ruptured (Figure 2 a) The more the displacement the more disruption was observed, and in two specimens with displacement there was rupture of the anastomoses between arteria canalis tarsi and arteria sinus tarsi (Figure 2 b)

### *Arteria dorsalis pedis*

The branches from the arteria dorsalis pedis descending to the talus were ruptured in their course through the fracture area No rupture of the arteria dorsalis pedis was observed (Figure 3)

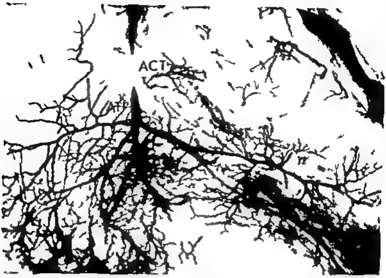


*Figure 2 a Angiogram of section II of left foot from a 17 year old boy after production of fracture which is slightly displaced Fracture line indicated by arrows The arteria canalis tarsi (ACT) is not here ruptured but becomes ruptured in its more anterolateral course (cf ACT Figure 2 b) ATP = arteria tibialis posterior (Spalteholz preparation)*

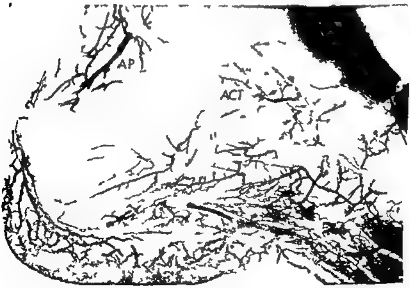


*Figure 2 b Same as Figure 2 a but section III The arteria canalis tarsi (ACT) has become ruptured at level of fracture (arrows) AP = arteria peronea (Spalteholz preparation)*

Figure 3 Angiogram of section II of left foot from a 45 year old woman Fracture of talus with displacement The descending vessels from the arteria dorsalis pedis (ADP) have been destroyed Only small remnants can be seen CV = capsular vessels in posterior capsule intact The calcaneus was fractured and displaced laterally (Spalteholz preparation)

*Arteria peronea*

This artery was never damaged by the fractures The ramus perforans from the arteria peronea became stretched in two cases, with localized disappearance of contrast medium, without evident rupture In the remaining specimens there was no damage to this artery

*Intra-osseous vessels*

The experimental fracture had a most destructive effect on the intra osseous arterial supply limited to the fracture region The vessels appeared as if they had been sharply cut off In the areas adjacent to the fracture site the vessels remained intact

*Interosseous vessels*

In five cases of talar neck fracture with no or only slight displacement there was no involvement of the capsular vessels In one case with great displacement there was a rupture of the anterior capsule vessels but none in the posterior capsule (Figure 3) The calcaneus was fractured and displaced laterally The arteries between the talus and the calcaneus and the navicular, respectively, were intact

## DISCUSSION

There are clinical implications that the experimentally produced fractures much resemble the mechanism of production as exemplified by the following case-history.

A 27-year old nurse was driving a car She noticed at some distance a car approaching which suddenly started skidding in a direction towards the nurse driver It became obvious to her that a head on collision was inevitable Realizing this she instantly pressed her left foot against the clutch and her right foot against the brake At the same time she stretched out her arms and pressed her hands against the wheel At the collision the nurse driver sustained a talar neck fracture in her right foot and a medial malleolar fracture in her left foot The clutch went down with the foot flat on the floor The brake, however, stopped at a distance from the floor and thus acted as an impact body at the moment of collision thus creating conditions similar to the experimental model by which talar neck fractures could be produced

The arterial supply of the talus under normal conditions has previously been studied (Wildenauer 1950, Haliburton et al 1958, Crock 1967, Mulfinger & Trueta 1970) It has become evident that a rich supply of arteries surround and furnish the talus It has been stated (Phemister 1940, McKeever 1943, Mindell et al 1963, Kenwright & Taylor 1970, Hawkins 1970) that an interruption of the supply by a fracture of the neck of the talus can have a deleterious effect on the osseous structure by the development of an avascular necrosis This is thought to be especially true in those cases where a displacement has occurred (Hawkins 1970, Kenwright & Taylor 1970, Brinkmann et al 1973)

In this investigation the object has been to study what effect a fracture of the neck of the talus may have on the arterial supply

Experimentally produced fractures without displacement showed ruptures of especially the intra-osseous arterial network The main contributing arteries to this network, i e arteria dorsalis pedis, rami deltoidei from the arteria canalis tarsi and this artery as well as the arteria sinus tarsi remained intact This no doubt has an effect on the future fate of the talar osseous structure The rate of avascular necrosis following non-displaced fractures is, as could be expected, very low e g 2 per cent (Brinkmann et al 1973), and in those cases where there is such a development it is hard to explain, considering the intact rich arterial supply from outside which no doubt can maintain the circulation of the bone

In displaced fractures the situation is quite different It has

previously been believed that a displaced fracture causes a disruption of the arterial supply to the body of the talus (Hawkins 1970, Kenwright & Taylor 1970, Brinkmann et al 1973) The results of this investigation disclosed that when a displaced fracture of the neck of the talus was produced, branches from the arteria dorsalis pedis were disrupted, as well as the arteria canalis tarsi and the arteria sinus tarsi In other words, what has been regarded as the main arterial supply to the talus becomes injured in a displaced fracture of the neck The degree of displacement is of some importance as it became evident that the more the displacement the more the vascular disarrangement Hence the development of avascular necrosis can be expected to be related to the degree of displacement, which has been verified clinically (Brinkmann et al 1973)

## SUMMARY

After filling the arteries of the talus with contrast medium, fractures of the neck were produced to study the effect on these vessels It was found that the ascending branches from the main arteries, arteria canalis tarsi and arteria sinus tarsi were ruptured in all cases The vessels in the fracture area were all sharply cut off Without fracture displacement the surrounding arteries were remarkably intact, whereas with displacement these became affected by varying degrees of disruption

The vessels in the bone adjacent to the fracture remained intact

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*Key words:* talus, experimental fracture; talus, blood supply.

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